FLOOD FLOW FREQUENCY FOR UNGAGED WATERSHEDS: A LITERATURE EVALUATION

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PREFACE

By direction of the Hydrology Committee of the U.S. Water Resources Council, a Work Group was formed to develop agreed upon sets of procedures for determination of peak flood flow frequencies for ungaged watersheds or gaged watersheds where systematic records are of insufficient length (generally less than 10 years) to warrant statistical analysis. The procedures are to be applicable to streams where there is negligible effect on the peak flows from man-made changes.

The Work Group is to select the procedures from those available from Federal agencies (Corps of Engineers, Bureau of Reclamation, Soil Conservation Service, Geological Survey, etc.) or those that are available in the published literature. Procedures should be applicable both to different regions and to catchment area sizes ranging from less than 1 square mile to several thousand square miles.

At meetings of the Hydrology Committee and during initial meetings of the Work Group, it was recognized that a means to test and compare some of the available procedures would have to be developed. For such a project, a review of the literature would be an important element. Under a cooperative agreement between the Agricultural Research Service and the University of Maryland, a search and evaluation of the literature was initiated about June 1, 1976. The cooperative agreement provided support for Mr. Gary T. Fisher for the period from June 1, 1976,to August 15, 1976. Dr. Richard H. McCuen and Mr. Robert L. Powell did not receive support. The Work Group met June 13-15, 1976, and their needs were outlined at this meeting. The evaluation was completed in June 1977.

This publication summarizes the literature review and evaluation that was performed to provide the Work Group with information that would be helpful in selecting procedures representative of those currently in use. Because of the specific objectives of this evaluation, the information included in the summaries does not necessarily describe all aspects of the articles.

Because of the short time frame of the study, omissions and errors were unavoidable and remain the responsibility of the authors. We would appreciate being informed of any omissions or errors.

ACKNOWLEDGMENTS

A project of this magnitude could not have been completed in such a short time without the aid of many. The authors would like to thank the other members and participants of the Work Group on Flood Flow Frequency Estimation at Ungaged Locations: Frederick A. Bertle, Bureau of Reclamation; William S. Bivins, U.S. Nuclear Regulatory Commission; David A. Falletti, Forest Service; Marshall Hansen, National Weather Service; Roy Huffman, Corps of Engineers; D. R. Jackson, Susquehanna River Basin Commission; James L. McGuinness, Agricultural Research Service; John F. Miller, National Weather Service; Norman Miller, Soil Conservation Service; Brian Mrazik, Federal Insurance Administration; Donald W. Newton (Chairman), Tennessee Valley Authority; Harvey H. Richardson, Soil Conservation Service; Donald M. Thomas, U.S. Geological Survey; Wilbert O. Thomas, Jr., U.S. Geological Survey; and Roy E. Trent, Federal Highway Administration for their help in locating pertinent articles and in reviewing this publication.

Special appreciation goes to Wilbert O. Thomas and Harvey W. Richardson for their efforts in collecting and reviewing papers for this literature evaluation. The authors also appreciate the response from numerous other professionals who responded to requests for articles and contributed copies of papers.

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FLOOD FLOW FREQUENCY FOR UNGAGED WATERSHEDS: A LITERATURE EVALUATION[1]

by Richard H. McCuen[2], Walter J. Rawls[3], Gary T. Fisher[4], and Robert L. Powell[5]

ABSTRACT

This report contains the results of an evaluation of recent publications on flood flow frequency estimation at ungaged locations. The objective of the literature evaluation was both to identify alternative procedures currently used for flood-frequency estimation at ungaged locations and to gather information regarding the accuracy, reproducibility, and practicality of the alternatives. The evaluation was limited to those studies involving watersheds that have not undergone man-made changes, such as urbanization or channelization. The procedures were separated into eight categories: (1) statistical estimation of Q_p, (2) statistical estimation of moments, (3) index flood estimation, (4) estimation by transfer of Q_p, (5) "empirical" equations, (6) single storm event:rain frequency is proportional to runoff frequency, (7) multiple discrete events, and (8) continuous record. Four important conclusions of this literature evaluation are: (1) there is a noticeable lack of consistency in the structure and presentation of results of hydrologic studies; (2) the literature does not accurately reflect what is currently being used in hydrologic planning and design; (3) the literature does not provide the information, such as cost and computer requirements, that is necessary for potential users to select a procedure from among the many that are in the literature; and

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(4) professional journals would better serve the profession if they would require authors to consider the criteria of accuracy, reproducibility, and practicality, and if they would adopt a consistent set of indices that reflect these criteria.

INTRODUCTION

The Work Group recognized that a literature review and evaluation would be an important aid in achieving their objectives. This publication summarizes the literature evaluation that was performed. The literature evaluation was designed specifically to provide the Work Group with information that would be helpful in selecting procedures that are representative of those currently in use.

The Work Group agreed that there are three criteria involved in the selection process: accuracy, reproducibility, and practicality. A selected procedure should give the highest degree of accuracy possible within the limitation of a practical procedure that achieves consistent results. It is not possible to detail the appropriate level for these three criteria. To the extent possible, standard measures of accuracy, i.e., standard errors of test results, should be used as a criterion to judge between procedures. Reproducibility can be enhanced by adopting procedures that require a minimum number of subjective decisions. Practicality, as measured, for example, by the cost of estimation and the time required to make an estimate, is an important criterion in procedure selection and must be weighed against the available resources. The selected procedures need not be restricted to those capable of field computation by individuals with limited experience and education.

CRITERIA FOR COMPARISON OF PROCEDURES

One objective of this study was to identify publications that described the evaluation of models on the basis of accuracy, reproducibility, and practicality, which are the three criteria established by the Work Group for comparing procedures. The following are definitions for these three criteria:

Accuracy: a measure of the closeness of the predicated values to the "true" value of the quantity being evaluated. It considers both precision and bias.

Reproducibility: a measure of the degree to which the predicted values of the quantity being evaluated by a group of individuals agree with each other.

Practicality: a measure of the effort and resources required to obtain an estimate of the quantity being evaluated.

Definitions of precision and bias, which are needed to define accuracy, are:

Precision: a measure of the random variation in a set of repeated estimates when the procedure is identically evaluated more than once.

Bias: a measure of the systematic error in a set of estimates that measures the deviation of the central tendency of these estimates from the "true" value.

CLASSIFICATION OF PROCEDURES

In order to select procedures from among the many that are currently in use, it is useful to first establish a classification scheme for categorizing procedures having common distinguishing characteristics. By grouping similar procedures, it is possible to select one or more procedures to represent each category and then test and compare the procedures. If the procedures selected are representative of those in the category, then the results may be used to draw inferences about the procedures in that category. The categories in the classification scheme should be different by at least one significant element. Hopefully, procedures assigned to a category would be similar in important characteristics, and differences in these characteristics should be apparent when comparing procedures assigned to different categories.

Authors use a variety of terms to describe procedures. Unfortunately, these terms, while descriptive, do not provide a sound basis for classifying procedures.

The Work Group considered the following methods for classification of flood flow frequency procedures. Most of the terms are derived from systems engineering and the representation of the system by "black-box" models. In the "black-box" analysis, the transfer function, input and output functions, and the method of calibrating the transfer function are fundamental.

Classification Using Characteristics of the Transfer Function

Systems are often characterized by the nature of the transfer function (i.e., model), which in systems theory is the function that transforms the input into the output function. Systems are often categorized with the following set of dichotomous terms: (1) deterministic vs. stochastic, (2) static vs. dynamic, (3) linear vs. nonlinear, (4) lumped vs. distributed, (5) time invariant and time-varying, and (6) conceptual and empirical. While these represent mutually exclusive categories, they are of limited value in classifying hydrologic models. They represent a limited scheme because there is wide variation in important characteristics of procedures that would fall within the same category. Thus, classification by characteristics of the transfer function is of limited value in classifying procedures used in flood peak estimation.

Classification by Method of Calibration

Very often the procedure includes unknown coefficients or parameters that were calibrated by the author of a publication or must be calibrated before using the model for estimation at ungaged sites. Three methods of model calibration (i.e., parameter optimization) are used: analytical, numerical, and subjective. All of these methods of calibration require the identification of an objective function, with analytical and numerical calibration requiring a quantitative statement of the objective function. Subjective calibration may include one or more quantitative and/or qualitative objective functions. The objective function represents a measure of the goodness-of-fit between observed and predicted values. The set of values of the unknown parameters that provide the "best fit," as determined by the objective function, are considered the optimum values, i.e., the objective function has been minimized or maximized. Thus the gradient of the objective function with respect to the unknown parameters equals zero at the optimum. The method by which the gradient is evaluated is the basis for classifying the model according to the method of calibration. This means of classification may be important because the degree of accuracy and reproducibility is affected by the method of calibration.

With analytical calibration, elements of differential calculus provide the basis for finding the optimum parameter values. This usually requires evaluation of the gradient, which is expressed using an explicit function. The optimum solution is found by expressing the gradient as an explicit function, setting it equal to zero, and then solving for the unknowns. The frequently used multiple regression techniques are examples of techniques that are calibrated analytically.

Numerical optimization is used when the gradient function cannot be specified as an explicit function, which frequently occurs when detailed models are used. In such cases, a feasible alternative is to evaluate the gradient using estimates of the objective function at a base point and for values of the parameters a small increment from the values at the base point. Numerical optimization is thus an iterative procedure in which movement is directed to a point where the gradient approaches zero. Numerical optimization requires a strategy. One effective strategy consists of three phases. The first phase is a exploration phase and involves the evaluation of the objective function at a large number of values of the unknowns to find a feasible base point. The second phase, which is a gradient climbing phase, uses an iterative evaluation of the gradient to approach the optimum; this becomes very ineffective as the gradient approaches zero. When the gradient approaches zero it is necessary to numerically evaluate the second derivatives of the objective function with respect to the unknowns because the nonlinear terms of the gradient function become important; this third phase is thus a combination of exploration and climbing. Numerical nonlinear least squares, the Rosenbrock technique, and the pattern search technique are frequently used as the second phase of a numerical optimization strategy.

Analytical and numerical optimization methods follow a systematic procedure in evaluating the unknowns. Also, these methods usually include only a single objective function.

Subjective optimization, which is a third method for calibrating a model, is frequently used for calibrating complex conceptual models. In this case, more than one objective function may be used in evaluating the unknowns, and the objective function(s) is not evaluated explicitly but it is implicit in the investigator's knowledge of the model. Thus, the subjective optimization procedure, which is not characterized by a systematic set of steps, is often not reproducible. Accurate estimates of the unknowns may usually be obtained only by someone with a thorough knowledge of the model and experience in calibrating the model.

A classification system that has categories defined solely by the method of calibration does not provide sufficient sensitivity to variation in accuracy, reproducibility, and practicality. However, it is an indicator of the cost (i.e., the practicality) of calibration and operation. Specifically, analytical methods are usually used for calibrating models that have relatively simple structures and data requirements. And, analytical calibration techniques are very efficient. It is usually less costly to use analytical techniques, when the models are capable of being calibrated with such techniques. Subjective calibration is usually reserved for the more complex conceptual hydrologic models, such as continuous simulation models.

Classification Using Input-Output Characteristics

Input requirements vary considerably for the available procedures and usually depend on the complexity of the model. For most hydrologic models, input requirements may consist of one or more of the following: precipitation observations, rainfall intensity-duration-frequency characteristics, watershed and land use characteristics (e.g., area, slope), soil-moisture information (e.g., antecedent precipitation index, infiltration rates), or temporal characteristics of the system (e.g., lag correlations).

If precipitation characteristics are required as input, it is sometimes necessary to specify the frequency of the event, sometimes with the implication that the frequency of the runoff event is the same as that of the precipitation. While many researchers have suggested that this is not a valid assumption, it still persists with a number of models.

Procedures and models that are commonly used to make flood estimates at ungaged locations may have any one of the following output functions: (1) a peak discharge of a specified frequency; (2) the total storm hydrograph of a specified frequency; (3) an outflow function that is continuous with time, from which the flood frequency curve is derived using the series of predicted annual maximums; (4) estimates of the moments (e.g., mean, variance, skew), from which the frequency curve is developed using some probability distribution function; (5) an estimate of a peak discharge of some specified index frequency and index ratios that can be used to estimate the flood magnitudes for other frequencies; and (6) an equation or set of coefficients that may be used to transfer a flood peak estimate from one location to the ungaged site.

Input/output is probably the most useful characteristic for classifying hydrologic models. The input requirements are often indicative of the practicality of using a model. Conceptual hydrologic models have relatively large input requirements and thus are usually not practical for small and less costly projects. Also the detail of the output often reflects the complexity of the model structure and the method of calibration, and thus, it is indicative of the accuracy of the procedure.

A Classification System

The classification system adopted by the Work Group represents a combination of the preceding methods of classification. The system has eight categories, each of which is expected to differ from the other categories in one or more of the three criteria: accuracy, reproducibility, and practicality. The eight categories are (1) statistical estimation of Q_p; (2) statistical estimation of moments; (3) index flood estimation; (4) estimation by transfer of Q_p; (5) empirical equations; (6) single storm event: rain frequency is proportional to runoff frequency; (7) multiple discrete events; and (8) continuous record. Table 1 summarizes for each of the eight categories the primary product from the procedure for meeting the objectives of the Work Group and any useful byproducts. Each of the procedures that was evaluated in this study was classified according to this system. For the most part, procedures were easily identified as belonging to one of the eight categories. Procedures that could be applied to techniques in more than one category are classified in the category expected to be used most frequently.

SUMMARY OF LITERATURE REVIEW

In an attempt to thoroughly peruse the literature, we used computer literature searches in addition to our manual searches. The computer data bases searched were those included in the Water Resources Scientific Information System (WRSIS), National Technical Information Service (NTIS), and the Agricultural Research Service Current Awareness Literature Search. Also, announcements soliciting published or unpublished articles were placed in publications of the following professional societies: American Society of Civil Engineers, American Water Resources Association, American Society of Agricultural Engineers, and American Geophysical Union. Individual requests were made to the Water Resources Centers and State water agencies.

Because of personnel and time limitations, some of the publications that were submitted for review were not evaluated. Some publications were judged not to be applicable to the specific objectives of the study, and others were very similar to other publications that had been evaluated. For example; the U.S. Geological Survey has independent peak flow estimation equations for each State; because these are often similar in both the development technique and results, only a few were evaluated. A detailed evaluation of those publications that we deemed applicable is given in the appendix.

Table 1.--Primary and useful byproducts of the eight categories

Category	Product	
	Primary[1/]	Other[2/]
1. Statistical estimation of Q_p	Q_p	
$Q_p = f$ (basin characteristics B, channel geometry G, climatic characteristic C)		
2. Statistical estimation of moments $Q_p = f$ (moments), moments $= f$ (B, G, C)	Frequency curve	
3. Index flood estimation $Q_p = f$ (ratio Q_i) $= Q_i = f$ (B, G, C)	Q_p	
4. Estimation by transfer of Q_p	Q_p	
5. Empirical equations	Q_p	
6. Single storm event: rain frequency $\propto$ runoff frequency	Q_p	Hydrograph possible
7. Multiple discrete events	Frequency curve	Flood hydrograph
8. Continuous record	Frequency curve	Continuous hydrograph

1/ The initial output from the procedure for meeting the objectives of the Work Group, either Q_p or the frequency curve.

2/ Useful byproducts, such as a flood hydrograph, of the procedure that may be of interest to some.

The evaluation is an abstraction of both content of the publication and information regarding the accuracy, reproducibility, and practicality of the techniques that can be used for flood flow frequency estimation at ungaged locations. Generally, the following information was evaluated for each publication: (1) bibliographic citation, (2) abstract, (3) classification according to the scheme developed by the Work Group, (4) location for which the procedure was developed, (5) input data requirements, (6) description of the data base used for calibration, (7) limitation of the data base, (8) calibration results, and (9) informative comments.

Table 2 summarizes the publications according to the classification system adopted by the Work Group, and table 3 separates the publications according to the location for which they were developed.

Table 2.--Publications by category

Category	Publication number[1/]
1. Statistical estimation of Q_p	3,4,5,7,8,11,15,18,26,32,33,34,41,42,44,49,52, 53,54,58,59,63,64,69,70,72,74,75,76,78,80,81,83, 84,85,96,97,100,101,102,103,104,106,110,116,121, 125,131,136,137,138,140,141,143,144,145,149,151, 155,156,157,162,164,172,179,181,182,183,196,203, 206,210,211,217,227,228,229,231,234,240
2. Statistical estimation of moments	60,77,79,129,178,208,216,221
3. Index flood estimation	12,16,23,47,57,68,71,133,150,165,166,174,175,176, 209,218,220,222,232
4. Estimation by transfer of Q_p	24,40,60,125,128,137,170,171
5. Empirical equations	2,10,20,28,67,86,87,88,89,135,142,180,189,194, 195,204,205,219,225,230
6. Single storm event: rain frequency $\propto$ runoff frequency	9,14,25,27,29,31,36,48,55,73,82,90,91,92,93,94,95, 99,107,112,115,119,120,127,130,134,148,152,159, 163,167,177,185,190,191,192,193,197,198,199,201, 207,215,223,226,239
7. Multiple discrete events	32,50,51,56,65,66,108,109,113,124,126,154,168, 188,232
8. Continuous record	19,21,39,46,97,98,114,117,118,122,123,132,139,146, 169,173,184,186,187,202,235

1/ Numbers refer to publications in the appendix.

Table 3.--Publications by location

Location	Publication number[1/]
Entire United States	11,40,46,50,60,62,77,78,79,88,114,128,129,146,147, 162,164,169,192,195,197,198,199,215,222,223,224,238
Eastern United States	86,87,155,156,191
Northeast United States	7
Southeast United States	194,204
Northwest United States	12,144,170,171
Western United States	193
Alabama	75,124,154
Alaska	19,20,21,22,26
Arizona	64,65,66,99,109,126,138,145,188
Arkansas	149,170
California	43,61,120,141,151,158,178,217
Colorado	8,84,85,125,150,170
Delaware	190,221
District of Columbia	3
Florida	15,186,205
Georgia	71,72,98,123,138,152
Hawaii	119,239
Idaho	24,143,172,181,209,217
Illinois	23,28,30,61,73,90,190
Indiana	49,73,151,190,206
Iowa	30,51,61,110,111,131,177
Kansas	106,170,189,190
Kentucky	76,132,170
Louisiana	8,140
Maine	61,83,137,190
Maryland	3,37,97,152,180,185,187,207,210,221,228
Massachusetts	101,229
Michigan	14,61
Minnesota	58,74,112
Mississippi	32,138,148
Missouri	61,73,80,81
Montana	53,57,103,104,105,175,176,234
Nebraska	5,73,138
Nevada	45,135,136,170,217
New Jersey	152,190,203,221
New Mexico	8,138,182,183
New York	174,190
North Carolina	29,54,61,96,138,139,152,187,235
North Dakota	41,42,58
Ohio	16,73,108,138,153,231
Oklahoma	52,138,159,179,211
Oregon	143,181,217,218,220
Pennsylvania	27,47,55,61,63,94,95,115,127,152,163,165,166,167,190, 206,208,210,214,221
Rhode Island	100

Table 3.--Publications by location--continued

Location	Publication number[1/]
South Carolina	117,118,152
South Dakota	4,31
Tennessee	10,157, 233
Texas	8,56,138,151,194
Utah	18,59,151,170, 173,225
Vermont	102,190
Virginia	3,97,107,133,138,152,184,210,221
Washington	44,143,181,217
West Virginia	68,69,210,212,213
Wisconsin	2,34,73,138,190,201,202
Wyoming	121,170,227
Australia	36,67,130
Canada	70,230
Cyprus	89
England	9, 240
New Zealand	142
Location not specified	1,6,13,17,25,33,35,38,39, 48, 82,91,92,93,113,116, 122,134,160,161,168, 196,200,216,219,226,237

1/ Numbers refer to publications in the appendix.

Other Literature Evaluations

The literature included comprehensive literature searches by Reich (160)[6/], Chow (28), and Bowers, Pabst, and Larson (13). These other literature searches provide additional summaries of publications on flood estimation. It is important to recognize that the objectives of these other literature searches were not the same as those of this evaluation.

Comparison of Procedures

Numerous publications described the use of more than one procedure. Some of these publications also provided a comparison of the results achieved using the different procedures. Table 4 lists publications that include discussions of more than one procedure. However, in some cases, the procedures are not compared as to their ability to predict peak discharge. It is unfortunate that the comparisons are all limited in some respect. For example, some publications involved data obtained for a very limited region while others involve

6/ Numbers in parentheses refer to publications in the appendix.

only a limited amount of data. Thus, it is impossible to provide statements about the accuracy, reproducibility, and practicality of either specific procedures or general values for each of the eight categories of the classification scheme.

Table 4.--List of publications comparing procedures

Publication number[1/]	Author	Year
1	Allison	1967
6	Benson	1962
10	Betson, Tucker, and Haller	1969
13	Bowers, Pabst, and Larson	1972
28	Chow	1962
35	Cordery and Pilgrim	1970
43	Cruff and Rantz	1965
61	Fleming and Franz	1971
62	Fletcher, Huber, Haws, and Clyde	1976
111	Lara	1974
153	Pickens	1977
158	Rantz	1971
160	Reich	1960
165	Reich and Jackson	1971
237	Woo	1974
238	World Meteorological Organization	1975

1/ Numbers refer to publications in the appendix.

Results of the Literature Evaluation on Accuracy

A major problem in literature evaluation was the lack of uniformity in the methodology and indices that were used to summarize the results of the studies. This makes it very difficult to compare the results of the studies. While some investigations compared techniques, very often the data base was limited; thus it is difficult to draw comparative inferences about the applicability of techniques.

In one of the more comprehensive studies that involved comparisons of techniques, the following indices were used for comparing the results (World Meteorological Organization *(238)*):

the coefficient of variation of the residual errors

$$Y = [(\sum_{i=1}^{m} y_{ci}-y_{oi})^2/m]^{1/2} / \bar{y}_o \qquad (1)$$

the ratio of the relative error to the mean

$$R = [\sum_{i=1}^{m} (y_{ci}-y_{oi})]/m\ \bar{y}_o \qquad (2)$$

the ratio of the absolute error to the mean

$$A = [\sum_{i=1}^{m} \left| y_{ci}-y_{oi} \right|]m\ \bar{y}_o \qquad (3)$$

where m is the number of events (i.e., peak discharges), y_{ci} and y_{oi} are the computed and observed discharges, respectively, and y_o is the mean of the observed peak discharges. It should be emphasized that these indices were evaluated for a single watershed; such indices were necessary because all of the models that were tested were designed for analyzing a continuous streamflow record.

While other quantitative indices have been used in the literature, there is a very noticeable lack of consistency in the use of goodness-of-fit indices. The correlation coefficient is frequently used as a goodness-of-fit index for flood peaks and as a measure of fit for hydrographs. Nonquantitative techniques, such as graphical displays of observed and predicted peaks, are also frequently used to summarize results.

CONCLUSIONS

One problem in compiling a literature search is the lack of consistency in the structure of the publications. For example, data requirements for a proposed procedure are often not clearly outlined, possibly because of space limitations imposed by the journals. A variety of indices of goodness-of-fit is used in reports; specifically, some publications use the correlation coefficient as a measure of fit while others use the standard error of estimate, sometimes in log units and sometimes in percentage form. Many publications present graphical comparisons of observed and computed values; graphical results are almost impossible to summarize in a literature evaluation and thus make it difficult to compare the results of different studies. A goal for future studies would be presentation of results in a manner that is consistent with current trends and that lends itself to comparison with the results of other studies.

One important observation that follows from this evaluation is that the literature does not adequately reflect what is currently being used. Instead, the literature contains many articles on experimental models that have been designed for a specific region or a specific problem. Thus, the volume of the literature on techniques that are currently being extensively used (e.g., the rational formula and the SCS technique) is not in proportion to the use of these techniques.

The most important conclusion of this literature evaluation is that the literature, while voluminous, does not contain sufficient information to provide a general statement about either specific procedures or general techniques as to their accuracy, reproducibility, or practicality. Thus, professionals in the hydrology and water resources disciplines need to develop and agree upon a set of indices to be used to summarize the results of hydrologic studies. At the very least, indices for accuracy, reproducibility, and practicality need to be established. Professional journals would better serve the profession if they would encourage authors to report such information and in a consistent manner. Specifically, cost, effort, input data requirements, and computer facility requirements are important to potential users, who are the ones journal articles are supposed to serve. Information on these four items is especially lacking in the literature.

APPENDIX — LITERATURE EVALUATIONS

1. Allison, S. V. 1967. Review of small basin runoff prediction methods. American Society of Civil Engineers Proceedings, Journal of the Irrigation and Drainage Division 93(IR1):1-6.

Abstract: Available methods of predicting peak discharge at ungaged location are discussed. The methods are separated into two categories: methods based on runoff records and methods based on rainfall records. Four principal problems of these methods are discussed: regional climatological differences, effects of differences in basin characteristics, the availability of relevant data, and problems of statistical significance. The author concludes that no simple, accurate, and universally applicable method exists. However, the data bases of statistical runoff frequency analysis appear to limit their value at the present time (1967) to predictions for larger basins (over 50 square miles). And for practicing engineers who have not had specialized training in hydrology, a simplified form of the SCS method still appears to offer the best opportunity for maximum use of available data, without seriously violating anything currently well-known about runoff phenomena.

Classification: Comparison of various techniques.

Location: Not specified.

Comments: None.

2. Ardis, C. V., K. J. Kueker, and A. T. Lenz. 1969. Storm drainage practices of thirty-two cities. American Society of Civil Engineers Proceedings, Journal of the Hydraulics Division 95 (HY1):383-408.

Abstract: The objective is to record the wide variation in storm drainage design practices, policies, and procedures in the State of Wisconsin. Thirty-two cities with 1960 populations of 6,000 or more responded to a survey that was made in early 1967. The survey was divided into two sections. Part A established basic background information and asked questions concerning design practice, policy, and cost. Part B requested a simple design be made for drainage of a six-block residential area assumed to be in the city. Based on 23 responses, the following conclusions are reported: (1) Most cities used the rational method, with only six cities using it correctly; (2) the runoff coefficient varied with soil type, with low values for clay loams and high values for sand and sand loams; (3) for the park in the design case, values of C ranged from 0.1 to 0.5 with a median value of 0.20; (4) for the shopping center in the design case, values of C ranged from 0.30 to 1.00, with a median value of 0.80; (5) where possible to determine, eight survey cities did not

consider flow time in the sewer system as part of the total time of concentration while eight cities did include it; (6) the total cost was highly correlated with the total number of manholes; (7) the total cost of drainage varied from less than $10,000 to more than $60,000, with the design layout being the fundamental cause for the significant variation in total cost.

Classification: Empirical equations.

Location: Wisconsin.

Comments: The results of this study are useful in assessing the reproducibility of the rational method.

3. Armentrout, C. L., and R. B. Bissell. 1970. Channel slope effect on peak discharge of natural streams. American Society of Civil Engineers Proceedings, Journal of the Hydraulics Division 96(HY2):307-315.

Abstract: Equations are given for predicting peak discharge as a function of the tangent slope. The equations are derived from data for 32 stations in Washington, D.C., and suburban areas in Maryland and Virginia.

Classification: Statistical estimation of Q_p.

Location: Maryland, Virginia, District of Columbia.

Input Data Requirements: Tangent slope (feet per mile).

Data Base for Calibration: 32 sites; minimum 14 years, average 24 years, maximum 41 years.

Limitations on Data Base: 1,337<area<522,800 acres, 2.2<slope<94 feet per mile.

Calibration Results: See Comments.

Comments: Measures of goodness-of-fit for calibration results were not given. A graph for Q_{50} shows the observed points and the prediction line. The prediction line is not a best-fit line; it is a line that envelops the maximum runoff values.

4. Becker, L. D. 1974. A method for estimating magnitude and frequency of floods in South Dakota. U.S. Geological Survey Water Resources Investigations 35-74, 78 pp. Huron, S. Dak.

Abstract: Two sets of regression equations are developed for return periods of 2, 5, 10, 25, 50, and 100 years. The first set relates watershed area and mean annual precipitation to peak discharge and is applicable to the eastern region

of South Dakota. The second set relates watershed area and mean basin elevation to peak discharge and is applicable to the western region. Adjustment is made for the sandhills area in the western region.

Classification: Statistical estimation of Q_p.

Location: South Dakota.

Input Data Requirements: East--area of watershed (square miles) and mean annual precipitation (inches of rainfall); West--area of watershed (square miles) and mean elevation of basin above sea level (feet).

Data Base for Calibration: East--52 sites; West--100 sites; average 19 years; minimum 10 years.

Limitations on Data Base: East--$0.1 \leq$ area of watershed $\leq 4{,}000$ square miles; West--$0.1 \leq$ area of watershed $\leq 9{,}000$ square miles.

Calibration Results: Average standard error: East--73 to 100 percent; West--63 to 134 percent.

Comments: The State was divided into two regions, East and West, the line of delineation being roughly the western divide of the James River Basin. Estimates of peak discharge for the sandhills, which are located along the Nebraska border in the West region, can be obtained by multiplying the result from the equations for the West by 0.4.

5. Beckman, E. W. 1976. Magnitude and frequency of floods in Nebraska. U.S. Geological Survey Water Resources Investigations 76-109. Lincoln, Neb.

Abstract: Regression analysis is used to determine flood peak for selected return periods using basin and meteorologic characteristics as input.

Classification: Statistical estimation of Q_p.

Location: Nebraska.

Comments: Not evaluated.

6. Benson, M. A. 1962. Evolution of methods for evaluating the occurrence of floods. U.S. Geological Survey Water Supply Paper 1580-A, 30 pp. Washington, D.C.

Abstract: A brief summary is given of the history of methods of expressing flood potentialities, from simple flood formulas to statistical methods of regional flood-frequency analysis.

Classification: Discussion of various techniques.

Location: Not specified.

Comments: Not evaluated.

7. Benson, M. A. 1962. Factors influencing the occurrence of floods in a humid region of diverse terrain. U.S. Geological Survey Water Supply Paper 1580-B, 64 pp. Washington, D.C.

Abstract: A multiple regression equation is developed, using topographic and climatic data to determine peak flow.

Classification: Statistical estimation of Q_p.

Location: New England States.

Input Data Requirements: Area of watershed (square miles); slope of main channel determined between 10 and 85 percent points of main channel length (feet per mile); surface storage area of ponds, lakes, and swamps (percent); orographic factor; average degrees Fahrenheit below freezing in January; T-year, 24-hour precipitation (inches).

Data Base for Calibration: 164 watersheds; 10-year minimum.

Limitations on Data Base: 10 square miles<area of watershed<9661 square miles; 2.5 feet per mile<slope of main channel determined between 10 and 85 percent points of main channel length<187 feet per mile.

Calibration Results: Standard error: 23.2 to 37.2 percent.

Comments: None.

8. Benson, M. A. 1964. Factors affecting the occurrence of floods in the Southwest. U.S. Geological Survey Water Supply Paper 1580-D, 72 pp. Washington, D.C.

Abstract: Two multiple regression equations are developed, using topographic and climatic data to determine peak flow. One equation is used in the region where floods are caused mainly by rainfall, and the other is used for the snowmelt flood area.

Classification: Statistical estimation of Q_p.

Location: Texas, Louisiana, New Mexico, Colorado.

Input Data Requirements: Area of watershed (square miles); slope of main channel determined between 10 and 85 percent points of main channel length (feet per mile); surface storage area of ponds, lakes, and swamps (percent); 10-year, 24-hour rainfall intensity; length of main channel (miles); runoff/rainfall for peak months; number of thunderstorms (days per year).

Data Base for Calibration: For rainfall events--155 watersheds; 10-year minimum.

Limitations on Data Base: 1.23 square miles $\leq$ area of watershed $\leq$ 35,293; 2.24 inches $\leq$ 10-year, 24-hour rainfall intensity $\leq$ 8.07 inches; 25 $\leq$ number of thunderstorm days per year $\leq$ 70.

Calibration Results: Standard error for rainfall events 107 percent each 1.2 years; 62-43 percent each 2.33-100 years.

Comments: None.

9. Beran, M. A. 1976. The use of input-output deterministic models to determine design flood frequencies. Paper presented at Conference on Mathematical Models in Hydrology, July 7, 1976, University of Lancaster, England.

Abstract: To assess the problem of assigning a return period to a computed flood peak, this paper discusses the experience of the United Kingdom Flood Studies in selecting the values of the inputs to a unit hydrograph/loss model of flood formation. With a simulation procedure that involves variation of the important model inputs, a single set of inputs can be chosen to yield the flood of any return period.

Classification: Single storm event: rain frequency $\propto$ runoff frequency.

Location: England.

Comments: Not evaluated.

10. Betson, R. P., R. L. Tucker, and R. M. Haller. 1969. Using analytical methods to develop a surface runoff model. Water Resources Research 5(1): 103-111.

Abstract: A mathematical expression is developed to represent the geographical surface-runoff model used by the National Weather Service. Comparison is made between the mathematical and graphical versions. After calibration, the model requires only rainfall volume, week of year, and antecedent precipitation index as inputs to determine direct runoff. Correlation coefficients range from 0.84 to 0.96 for the 4 test basins.

Classification: Empirical equations.

Location: Tennessee.

Input Data Requirements: Total rainfall per event; season index, varies with week of year; recurrence interval; antecedent precipitation index.

Data Base for Calibration: 10 watersheds; 28 to 166 storm events.

Limitations on Data Base: $37.8 \leq$ area of watershed $\leq 1{,}784$ square miles.

Calibration Results: Range of statistics for mathematical model--sum of the squares of errors 1.66 to 3.74, correlation coefficient 0.89 to 0.98; range of statistics for test results of four watersheds--sum of the squares of errors 2.72 to 8.72, correlation coefficient 0.84 to 0.96.

Comments: Each watershed was calibrated separately, and transferability tests were made by applying one of three equations to each of four other watersheds. A test was made to extend a record 2 years by using an equation developed from the previous 8 years of data, giving a sum of the squares of errors of 0.27 and a correlation coefficient of 0.92.

11. Bock, P., I. Enger, G. P. Malhotra, and D. A. Chisholm. 1972. Estimating peak runoff rates from ungaged small rural watersheds. Report No. 136, 87 pp. National Cooperative Highway Research Program, Highway Research Board, Washington, D.C.

Abstract: Paper presents derivation of 84 equations for peak flow prediction and the selection of a set of three best for nationwide application. When compared with formulas used by 31 States, the three are found to be at least as good, in the majority of cases. The first set of equations predicts Q_{10}, Q_{25}, and Q_{50} as a function of six parameters and a regional variable. The second set of equations uses four predictor variables for estimating Q_{10}, Q_{25}, and Q_{50}. The third set of equations can be used to estimate the mean annual flood.

Classification: Statistical estimation of Q_p.

Location: Entire United States.

Input Data Requirements: Equation 1--length of main channel (miles); total length of tributaries (miles); 60-minute rainfall intensity (inches) for designated frequency; mean annual flood (cubic feet per second) (return period= 2.33 years); factor which varies with geographic region; watershed shape factor; mean July temperature (degrees Fahrenheit); equation 2--area of watershed (square miles); 60-minute rainfall intensity (inches) for designated frequency; mean annual flood (cubic feet per second)(return period = 2.33 years); factor which varies with geographic region; mean July temperature (degrees Fahrenheit); equation 3--travel time index; mean annual temperature (degrees Fahrenheit); total length of tributaries (miles); number of rainfall days; mean annual snowfall (inches); area of watershed (square miles); potential evapotranspiration (inches); number of freezing days (below 32 degrees

Fahrenheit); number of thunderstorms (days per year); elevation of gage above sea level (feet); length of main channel (miles); maximum 24-hour rainfall (inches); slope of main channel; drainage density (miles -1); watershed shape factor; mean July temperature (degrees Fahrenheit).

Data Base for Calibration: 493 watersheds; mean 18.3 years, minimum 12 years.

Limitations on Data Base: Not specified.

Calibration Results: Not summarized.

Comments: Applicable only to rural watersheds with area less than 25 square miles.

12. Bodhaine, G. L., and D. M. Thomas. 1964. Magnitude of frequency of floods in the United States: Part 12, Pacific Slope Basins of Washington and Upper Columbia River Basin. U.S. Geological Survey Water Supply Paper 1687, 337 pp. Washington, D.C.

Abstract: The index flood method is used to provide estimates of peak discharge for watersheds in the Northwest. The mean annual flood, which is used as the index flood, can be estimated using a regression relationship on basin characteristics.

Classification: Index flood estimation.

Location: Pacific Slope Basins and Columbia River Basins.

Input Data Requirements: Mean annual flood (cubic feet per second) (return period = 2.33 years); area of watershed (square miles); surface storage area of ponds, lakes, and swamps (percent); factor which varies with geographic region.

Data Base for Calibration: All stream-gaging stations with 5 years or more of annual peak record.

Limitations on Data Base: Drainage areas greater than 0.1 and 20 square miles for Pacific Slope Basins and the Upper Columbia River Basin, respectively.

Calibration Results: Standard error of estimate--Columbia River, 24 percent; Pacific Slope, 23 percent; coefficient correlation =0.99.

Comments: The study area is divided into eight regions, each considered to have homogeneous flood characteristics. In regions 7 and 8 adjustment must be made to the ratio. Regression coefficients and exponents differ for Upper Columbia River Basin and Pacific Slope Basins.

13. Bowers, C. E., A. F. Pabst, and S. P. Larson. 1972. Computer programs in hydrology. Water Resources Research Center Bulletin No. 44, 172 pp. University of Minnesota, Minneapolis.

Abstract: The objective is to review selected computer programs in the field of hydrology with the aim of assisting in the application of these programs by potential users. Abstracts for 25 programs are given, each containing the source, description, methods used, and a brief discussion of the program's potential use.

Classification: Discussion of various techniques.

Location: Not specified.

Comments: Not evaluated.

14. Brater, E. G., and J. D. Sherrill. 1975. Rainfall-runoff relations on urban and rural areas. National Environmental Research Center, U.S. Environmental Protection Agency, 95 pp. Cincinnati, Ohio.

Abstract: A unit hydrograph procedure is given for determining the frequency of storm runoff on small drainage basins. The method is calibrated using 1,620 storm events on 69 basins in Texas, Michigan, Kentucky, Illinois, and Maryland. The form of the unit hydrograph is related to drainage basin size and the degree of urbanization, as measured by population density. Infiltration and retention are accounted for, with infiltration varying seasonally.

Classification: Single storm event: rain frequency$\propto$runoff frequency.

Location: Southeastern Michigan.

Input Data Requirements: Not summarized.

Data Base for Calibration: 69 watersheds; 1,620 storm events.

Limitations on Data Base: $0.02 < \text{area} < 734$ square miles.

Calibration Results: Graphical.

Comments: 54 of the 69 basins have areas less than 20 square miles.

15. Bridges, W. C. 1977. Progress report on study of magnitude and frequency of floods on small drainage areas in Florida. U.S. Geological Survey, unpublished open-file report, 27 pp. Tallahassee, Fla.

Abstract: Regression analysis is used to determine flood peak for selected return periods using basin and meteorological characteristics as input.

Classification: Statistical estimation of Q_p.

Location: Florida.

Comments: Not evaluated.

16. Bureau of Public Roads. 1961. Estimating peak rates of runoff from small watersheds in Ohio. U.S. Department of Commerce Hydraulic Engineering Circular No. 4 (Ohio), 13 pp. Washington, D.C.

Abstract: A graphical procedure is provided for estimating the 10-year peak discharge as a function of the area, length of main channel, and a precipitation index that varies with geographic location. Graphs are provided for finding Q_{25}, Q_{50}, and Q_{200} from the estimated value of Q_{10}.

Classification: Index flood estimation.

Location: Ohio.

Input Data Requirements: Drainage area in thousands of acres; a precipitation index (map provided); length (miles) of the principal stream; latitude and longitude of the site.

Data Base for Calibration: Not specified.

Limitations on Data Base: $10 \leq Q_{10} \leq 800$ cubic feet per second.

Calibration Results: Standard error of estimate of 20 percent.

Comments: None.

17. Burkhardt, G., and A. Prakash. 1976. An application of computer graphics to analysis of extremes. Water Resources Bulletin 12(6):1245-1258.

Abstract: For the log-Pearson Type III distribution, the probability paper is characterized by a population-specific parameter, namely, the coefficient of skewness. Because it is not practical to procure probability papers for all possible values of the parameters, a computer program was developed to generate population-specific probability papers to perform statistical analyses of data, using computer graphics. The computer graphic technique also provides for other distributions, the double exponential and the bounded exponential distributions, as well as plotting of data points and fitting linear regression lines to data points.

Classification: Not classified.

Location: Not specified.

Comments: Not evaluated.

18. Butler, E., and R. W. Cruff. 1971. Floods of Utah, magnitude and frequency characteristics through 1969. U.S. Geological Survey, unpublished open-file report, Salt Lake City, Utah.

Abstract: Regression analysis is used to determine flood peak for selected return periods using basin and meteorologic characteristics as input.

Classification: Statistical estimation of Q_p.

Location: Utah.

Comments: Not evaluated.

19. Carlson, R. F. 1972. Development of a conceptual hydrologic model for a sub-arctic watershed. Institute of Water Resources Report No. IWR-28, 58 pp. University of Alaska, Fairbanks.

Abstract: A conceptual model is presented; it includes six parameters and the following processes: evapotranspiration, surface storage, channel storage, soil moisture accounting, percolation, and ground water storage. The model is evaluated, using data from a 40-square-mile watershed in Alaska. The relative importance of the parameters is evaluated.

Classification: Continuous record.

Location: Alaska.

Comments: Not evaluated.

20. Carlson, R. F., and P. Fox. 1974. Flood frequency estimation in northern sparse data regions. Institute of Water Resources Report No. IWR-55, 15 pp. University of Alaska, Fairbanks.

Abstract: Research results on flood frequency estimation in northern sparse-data regions are summarized. A decision flow diagram is presented for selecting a method for various levels of data availability.

Classification: Empirical equations.

Location: Alaska.

Comments: Not evaluated.

21. Carlson, R. F., and P. Fox. 1976. A northern snowmelt-flood frequency model. Water Resources Research 12(4):786-794.

Abstract: A rainfall-flood frequency model is examined and converted to a snowmelt-flood frequency model for use in northern subarctic regions. The model is applied to the Chena River at Fairbanks with emphasis on evaluation of the model for use on watersheds with few or no previous discharge records.

Classification: Continuous record.

Location: Alaska.

Comments: Not evaluated.

22. Carlson, R. F., P. M. Fox, and S. D. Shrader. 1974. Methods of flood flow determination in sparse data regions. Institute of Water Resources Report No. IWR-52, 37 pp. University of Alaska, Fairbanks.

Abstract: The applicability of the following three methods for peak flow estimation at ungaged sites in Alaska is qualitatively examined: empirical formulas, frequency analysis, and regression techniques.

Classification: Discussion of various techniques.

Location: Alaska.

Comments: Not evaluated.

23. Carns, J. M. 1973. Magnitude and frequency of floods in Illinois. 599 pp. State of Illinois, Department of Transportation, Division of Water Resources Management, Champaign, Ill.

Abstract: Regression equations for return periods from 1.25 to 100 years are derived for predicting peak discharge as a function of area, slope, rainfall intensity index, and a factor that varies with the region, with standard errors from 32 to 45 percent. Index flood ratios are provided for determining the 50- and 100-year floods for drainage areas less than 25 square miles.

Classification: Index flood estimation.

Location: Illinois.

Input Data Requirements: Area of watershed (square miles); slope of main channel determined between 10 and 85 percent points of main channel length (feet per mile); maximum 2-year, 24-hour rainfall intensity (inches); factor which varies with geographic region (maps provided).

Data Base for Calibration: 294 watersheds; 10 or more years.

Limitations on Data Base: $0.02 \leq$ area of watershed $\leq 28{,}600$ square miles; $0.69 \leq$ slope of main channel determined between 10 and 85 percent points of main channel length ≤ 269.81 feet per mile; $2.7 \leq$ maximum 2-year, 24-hour rainfall ≤ 3.6 inches.

Calibration Results: Standard errors for the regression equations ranged from 32.6 to 44.6 percent; standard errors for the index flood ratios are 48.1 and 51.5 percent.

Comments: None.

24. Carrigan, P. H., Jr. 1971. A flood-frequency relation based on regional record maxima. U.S. Geological Survey Professional Paper 434-F, 122 pp. Washington, D.C.

Abstract: A means of estimating the exceedance probability for rare flood events by the simultaneous consideration of concurrent records of annual extremes is presented. The reliability (i.e., the effective sample size) is increased because the random variations of flood intensity in both time and space are accounted for.

Classification: Estimation by transfer of Q_p.

Location: Idaho. See Comments (1).

Input Data Requirements: Coefficients of variation and skew, kurtosis, maximum flood.

Data Base for Calibration: Six watersheds; 45-48 years.

Limitations on Data Base: Not specified.

Calibration Results: None.

Comments: (1) The method was tested using six gages in Idaho. However, it is applicable anywhere (when the statistical assumptions are not violated). (2) The solution is derived with Monte Carlo simulation, rather than an analytical solution.

25. Chiang, S. L. 1972. A rational approach to flood hydrograph synthesis. Paper presented at the 20th Annual Speciality Conference of American Society of Civil Engineers, 9 pp. Ithaca, N. Y.

Abstract: A method is proposed for determining the design hydrograph and discharge. The method requires regional estimates of peak discharges for return periods of 2.33 and 100 years.

Classification: Single storm event: rain frequency $\propto$ runoff frequency.

Location: Not specified.

Comments: Not evaluated.

26. Childers, J. M. 1970. Flood frequency in Alaska. U.S. Geological Survey, unpublished open-file report, 30 pp. Anchorage, Alaska.

Abstract: Regression analysis is used to determine flood peak for selected return periods using basin and meteorologic characteristics as input.

Classification: Statistical estimation of Q_p.

Location: Alaska.

Comments: Not evaluated.

27. Chiu, C. L., and R. P. Bittler. 1969. Linear time-varying model of rainfall-runoff relation. Water Resources Research 5(2):426-437.

Abstract: The linear, time-varying system model of the rainfall-runoff relation can be represented by a first-order, linear differential equation with time-varying coefficients that depend on two parameters. The model does not require the time-variance assumption necessary in the conventional unit hydrograph method. The developed model and techniques used in the experimental study to describe and predict the rainfall-runoff relation have proved satisfactory.

Classification: Single storm event: rain frequency $\propto$ runoff frequency.

Location: Pennsylvania.

Input Data Requirements: Values for two empirical parameters.

Data Base for Calibration: One watershed (area = 257 square miles); 28 storm events.

Limitations on Data Base: Not specified.

Calibration Results: Tabular and graphical summary.

Comments: None.

28. Chow, V. T. 1962. Hydrologic determination of waterway areas for the design of drainage structures in small drainage basins. University of Illinois Engineering Experiment Station Bulletin No. 462, 104 pp. Urbana, Ill.

Abstract: A method is presented for estimating peak runoff for rural watersheds in Illinois, for recurrence intervals of 5, 10, 25, 50, and 100 years. Only topographic and land use data are needed as input. The report gives all necessary charts and graphs for use in design. The report also presents a listing of 66 other prediction methods developed before 1960.

Classification: Empirical equations.

Location: Illinois.

Input Data Requirements: Runoff factor; climatic factor; peak reduction factor; area of watershed.

Data Base for Calibration: Not specified.

Limitations on Data Base: 20 basins used for study of lag time; $2.79 \leq$ area of watershed $\leq 4,580$ acres.

Calibration Results: None.

Comments: The peak flow predicted is that due to surface runoff only. Baseflow must be added to obtain total runoff.

29. Chow, V. T., and S. Ramaseshan. 1965. Sequential generation of rainfall and runoff data. American Society of Civil Engineers Proceedings, Journal of the Hydraulics Division 91(HY4):205-223.

Abstract: From 28 years of rainfall data on the French Broad River Basin, 1,000 storms are synthetically generated sequentially and routed through the simulated basin to produce 1,000 floods. A comparison between simulated and actual peaks indicates good agreement between 40 and 90 percent probability of occurrence.

Classification: Single storm event: rain frequency $\propto$ runoff frequency.

Location: North Carolina.

Input Data Requirements: Not specified.

Data Base for Calibration: One watershed; 28 years.

Limitations on Data Base: Not specified.

Calibration Results: Not specified.

Comments: "Sequential generation is a statistical process using Monte Carlo methods to produce a random sequence of hydrologic data on the basis of a stochastic model for the hydrologic process..." (p. 210). From the rainfall data 1,000 storms were generated and routed through the simulated basin to produce 1,000 floods by convolution with an instantaneous unit hydrograph that is represented by a gamma distribution function.

30. Chow, V. T., and N. Takase. 1977. Design criteria for hydrologic extremes. American Society of Civil Engineers, Journal of the Hydraulics Division 103(HY4): 425-436.

Abstract: Paper presents an empirical examination of the applicability of elements of the theory of probability to the analysis of hydrologic extremes.

Classification: Not classified.

Location: Iowa, Illinois.

Comments: Not evaluated.

31. Chu, S. T., and W. F. Lytle. 1972. Time of base for watersheds in South Dakota. American Society of Agricultural Engineers Transactions 15(2): 276-279.

Abstract: A method for estimating peak discharge for given rainfall recurrence interval, based upon SCS method and unit hydrograph theory, is presented.

Classification: Single storm event: rain frequency $\propto$ runoff frequency.

Location: South Dakota.

Input Data Requirements: Base time of hydrograph; area of watershed; coefficient which relates peak discharge to basin area, rainfall, and base time; 60-minute rainfall.

Data Base for Calibration: 23 watersheds; 193 hydrographs.

Limitations on Data Base: $0.18 \le$ area of watershed ≤ 530 square miles; $0.5 \le$ base time of hydrograph ≤ 141.7 hours; $0.75 \le$ length of main channel ≤ 57.4 miles; $0.0010 \le$ slope of main channel ≤ 0.0290.

Calibration Results: Correlation coefficient equals 0.982.

Comments: The base time of the hydrograph is a function of the length of main channel and the slope of main channel.

32. Colson, B. E., and J. W. Hudson. 1976. Flood frequency of Mississippi streams. U.S. Geological Survey for the Mississippi State Highway Department, Jackson, Miss.

Abstract: Regression relationships are derived for peak discharges having return periods from 2 to 100 years. Synthetic data for 89 stations are developed using a rainfall-runoff model. Records for 221 stations are also used. Standard errors are from 32 to 44 percent.

Classification: (1) Multiple discrete events and (2) statistical estimation of Q_p.

Location: Mississippi.

Input Data Requirements: Area of watershed; slope of main channel determined between 10 and 85 percent points of main channel length; length of main channel.

Data Base for Calibration: 82 stations with 25 or more years; 95 stations with an average of 10 years.

Limitations on Data Base: $0.04 \leq \text{area} \leq 6{,}630$ square miles.

Calibration Results: Not specified.

Comments: Log-Pearson Type III frequency analysis was made of gaged data, and values for Q_t (t = 2, 5, 10, 25, 50, 100) are tabulated.

33. Commons, G. G. 1961. The Myers formula and Myers rating compared with actual floods. Geophysical Research Journal 66(12):4322-4323.

Abstract: This paper examines the validity of the Myers formula, which expresses peak discharge as a function of drainage area. Conclusions are (1) that the maximum recorded flows do not vary as the square root of the area; (2) it is not useful when applied to watersheds of different areas; and (3) its use as a means of comparing flood flows should be discontinued.

Classification: Statistical estimation of Q_p.

Location: Not specified.

Comments: Not evaluated.

34. Conger, D. H. 1976. Estimating magnitude and frequency of floods in Wisconsin. U.S. Geological Survey, unpublished open-file report, Madison, Wis.

Abstract: Regression equations are given, relating peak discharge of return 2, 5, 10, 25, 50, and 100 years to drainage area, channel slope, and lake area. These equations provide errors from 33 to 40.6 percent. Using only basin area and lake area as predictors, the standard errors range from 36.4 to 43 percent. Frequency curves are presented for some regulated streams. The State is separated into two regions.

Classification: Statistical estimation of Q_p.

Location: Wisconsin.

Input Data Requirements: Region 1--area of watershed (square miles); slope of main channel determined between 10 and 85 percent points of main channel length (feet per mile); surface storage areas of ponds, lakes, and swamps (percent); factor which varies with geographic regions. Region 2--area of watershed (square miles); surface area of ponds, lakes, and swamps (percent); factor which varies with geographic regions.

Data Base for Calibration: 233 watersheds; 6-year minimum.

Limitations on Data Base: $0.33 \leq$ area of watershed $\leq 6{,}290$ square miles; $0.84 \leq$ slope of main channel determined between 10 and 85 percent points of main channel length ≤ 270 feet per mile; $0 \leq$ surface storage area of ponds, lakes, and swamps ≤ 39.7 percent.

Calibration Results: Standard errors are 33.0 to 40.6 percent for region 1 and 36.4 to 43.0 percent for region 2.

Comments: For smaller drainage areas, the index flood method should be used. Index flood relationships are provided.

35. Cordery, I., and D. H. Pilgrim. 1970. Design hydrograph methods of flood estimation for small rural catchments. Paper No. 2832. Civil Engineering Transactions, 1974. The Institution of Engineers, Australia.

Abstract: Published design hydrograph procedures for flood estimation on small rural catchments are reviewed, but not tested.

Classification: Discussion of various techniques.

Location: Not specified.

Comments: Not evaluated.

36. Cordery, I., and S. N. Webb. 1974. Flood estimation in eastern New South Wales--a design method. Paper No. 3265. Civil Engineering Transactions, 1974, pp. 87-93. The Institution of Engineers, Australia.

Abstract: The proposed method uses the loss rate-unit hydrograph approach to flood estimation, where the unit hydrograph is derived synthetically and the rainfall excess is derived from available records. Two model parameters must be derived from catchment characteristics and are used to derive a synthetic unit hydrograph.

Classification: Single storm event: rain frequency$\propto$runoff frequency.

Location: Australia.

Input Data Requirements: Length, slope, duration, drainage area.

Data Base for Calibration: Not specified.

Limitations on Data Base: Not specified.

Calibration Results: Graphical.

Comments: None.

37. Costa, J. E. 1974. Stratigraphic, morphologic, and pedologic evidence of large floods in humid environments. Geology 6(6):301-303.

Abstract: The paper discusses the use of stratigraphic, morphologic, and pedologic evidence in the prediction of very large floods. Mappable alluvial soils delineate only areas affected by moderate floods with recurrence intervals of less than 50 years.

Classification: Not classified.

Location: Maryland.

Comments: Not evaluated.

38. Coulson, A. 1966. Tables for computing and plotting flood frequency curves. Technical Bulletin No. 3, 16 pp. Water Resources Branch, Department of Energy, Mines and Resources, Ottawa, Ont., Canada.

Abstract: Tables are provided for computing flood frequency curves and confidence limits for the curve. Basis is Gumbel's method; no calibration information is provided.

Classification: Not classified.

Location: Not specified.

Comments: Not evaluated.

39. Crawford, N. H., and R. K. Linsley. 1966. Digital simulation in hydrology: Stanford watershed model IV. Department of Civil Engineering Stanford University Technical Report No. 39, 208 pp. Stanford, Calif.

Abstract: Paper gives detailed presentation on the structure, input requirements, and the application of the Stanford watershed model.

Classification: Continuous record.

Location: Not specified.

Comments: Not evaluated.

40. Crippen, J. R., and D. B. Conrad. 1977. Maximum floodflows in the conterminous United States. U.S. Geological Survey Water Supply Paper 1887, 51 pp. Washington, D.C.

Abstract: Peak floodflows from thousands of observation sites within the conterminous United States are studied to provide a guide for estimating potential maximum floodflows. Data are selected from 883 sites with drainage areas of less than 10,000 square miles (25,900 square kilometers) and are grouped into regional sets. Outstanding floods for each region are plotted on graphs, and envelope curves are computed that offer reasonable limits for estimates of maximum floods.

Classification: Estimation by transfer of Q_p.

Location: Entire United States.

Comments: Not evaluated.

41. Crosby, O. A. 1974. An investigation of basin effects on flood discharges in North Dakota. U.S. Geological Survey, unpublished open-file report 74-346, 49 pp. Bismarck, N. Dak.

Abstract: The relationship of peak discharge to causative storm variables and basin characteristics is investigated. The procedure involves the estimation of peak discharge on 11 study basins using multiple regression to relate storm variables and basin characteristics to peak discharge, with particular attention given to the effect of basin shape.

Classification: Statistical estimation of Q_p.

Location: North Dakota.

Input Data Requirements: Total precipitation (inches); rainfall distribution index; duration of rainstorm (hours); antecedent discharge (cubic feet per second); shape factor; slope (feet per mile).

Data Base for Calibration: 11 watersheds.

Limitations on Data Base: 17<area<58.1 square miles.

Calibration Results: Standard errors range from 65 to 119 percent. See Comments (2).

Comments: (1) North Dakota was divided into two regions corresponding to glacial history. (2) Large standard errors are due to an oversimplification of storm parameters as well as varying influence on peak discharge with storm magnitude. (3) The procedure is not applicable for discharges resulting from snowmelt, ice backwater, or frozen ground.

42. Crosby, O. A. 1975. Magnitude and frequency of floods in small drainage basins in North Dakota. U.S. Geological Survey Water Resources Investigations 19-75, 24 pp. Bismarck, N. Dak.

Abstract: Paper develops three sets of regression equations for return periods of 2, 5, 10, 25, and 50 years, with each set applicable to a separate region of North Dakota. Two sets of equations use watershed area and a soil infiltration index to predict peak discharge, and the third uses area only. Standard errors range from an average of 62 to 86 percent.

Classification: Statistical estimation of Q_p.

Location: North Dakota.

Input Data Requirements: Region A--area of watershed (square miles); soil infiltration index (inches); Region B--area of watershed (square miles); soil infiltration index (inches); Region C--area of watershed (square miles).

Data Base for Calibration: Not specified.

Limitations on Data Base: Not specified.

Calibration Results: Average standard error for region A, 62 to 86 percent; B, 64 to 84 percent; C, 67 to 85 percent.

Comments: None.

43. Cruff, R. W., and S. E. Rantz. 1965. A comparison of methods used in flood-frequency studies for coastal basins in California. U.S. Geological Survey Water Supply Paper 1580-E, 56 pp. Washington, D.C.

Abstract: Three methods are compared, the index flood, multiple regression, and moment estimation, with four different probability distributions tested using the last method. A humid and subhumid region in California were used as study areas. The results indicate that regression provides the most reliable results for estimating the 50-year and 100-year peaks.

Classification: Comparison of various techniques.

Location: California.

Input Data Requirements: Coast: area of watershed (square miles); mean annual precipitation (inches); mountains: area of watershed (square miles); watershed shape factor.

Data Base for Calibration: Coast: five and eight watersheds; mountains: 18 watersheds; record length 10 to 50 years.

Limitations on Data Base: Not available.

Calibration Results: Not available.

Comments: None.

44. Cummans, J. E., M. R. Collings, and E. G. Nassar. 1975. Magnitude and frequency of floods in Washington. U.S. Geological Survey, unpublished open-file report 74-336, 46 pp. Tacoma, Wash.

Abstract: Two sets of regression equations are developed for return periods of 2, 5, 10, 25, 50, and 100 years, relating area, annual precipitation, and forest cover to peak discharge. The first is applicable to the western part of the State and the second to the eastern. The regression coefficients are uniquely determined for each of 12 separate regions of the State.

Classification: Statistical estimation of Q_p.

Location: Washington.

Input Data Requirements: Eastern region--area of watershed (square miles); forest cover factor (percent); mean annual precipitation (inches of rainfall); Western region--area of watershed (square miles); mean annual precipitation (inches).

Data Base for Calibration: 450 watersheds (see Comments); 10-year minimum.

Limitations on Data Base: $0.15 \leq$ area $\leq 3{,}550$ square miles; $0.01 \leq$ forest cover factor ≤ 100 percent; 10 inches $\leq$ mean annual precipitation (rainfall) ≤ 201 inches.

Calibration Results: Standard error of estimate for Western region is 24.6 to 60.7 percent; for Eastern, 41.7 to 129 percent.

Comments: Two sets of regression equations are presented for peak flow prediction. The first, applicable to the western part of the State, uses only area and mean annual precipitation as predictors. The second applies to the eastern part of the State. In addition, the State is divided into 12 regions with the regression coefficients being uniquely determined for each. Records from 450 gaging stations were used for the entire study. It is not stated how many were applied to each region.

45. Cunningham, A. B. 1975. Evaluation of flood peak prediction methods in northern Nevada in relation to dam safety. Project No. 29, 41 pp. Center for Water Resources Research, Desert Research Institute, Reno, Nev.

Abstract: A regional flood frequency analysis is made of 24 Nevada watersheds using the best fit of 10 probability distributions to historic data. From derived flood frequency diagrams, 2-, 10-, and 50-year floods are determined and compared with values predicted by five commonly accepted methods of peak flow prediction.

Classification: Comparison of various techniques.

Location: Nevada.

Comments: Not evaluated.

46. Curtis, D. C., and G. F. Smith. 1976. The National Weather Service River Forecast System - Update 1976. Hydrologic Research Laboratory (W23), 14 pp. National Weather Service, Silver Spring, Md.

Abstract: Report describes the National Weather Service River Forecast System, which is a continuous simulation model.

Classification: Continuous record.

Location: Entire United States.

Comments: Program has a modular structure so components can be added, dropped, or modified at any time. Because the publication does not provide all information, it is suggested that the National Weather Service be contacted for current information on components and uses. The Sacramento River Forecast Model is used for soil moisture accounting.

47. Dalrymple, T. 1960. Flood-frequency analysis: Manual of hydrology. U.S. Geological Survey Water Supply Paper 1543-A.

Abstract: A method of defining a frequency curve for an ungaged site is outlined. The method requires the evaluation of mean flood ratios, the ratio of flood flows of selected exceedance probabilities to the mean annual flood. A relationship between the mean annual flood and watershed characteristics (e.g., drainage area) is also required.

Classification: Index flood estimation.

Location: Southern Pennsylvania.

Input Data Requirements: Area of watershed.

Data Base for Calibration: 15 stations, 11 to 69 years.

Limitations on Data Base: 3<area<1,723 square miles.

Calibration Results: Not specified.

Comments: Only pages 25-47 are summarized in this study. The procedure is to fit frequency curves to data from stations in the region, determine the mean annual floods, and relate these to watershed characteristics (e.g., drainage area); also average ratios between selected flows for other return periods and the mean annual flood are determined.

48. Dalrymple, T., and M. A. Benson. 1967. Measurement of peak discharge by the slope-area method. Chapter A2, in Techniques of Water-Resources Investigations of the U.S. Geological Survey. Book 3, Applications of Hydraulics, 12 pp. Washington, D.C.

Abstract: Maximum peak discharge for a stream is estimated by applying the Manning equation to data derived from high water marks.

Classification: Single storm event: rain frequency$\propto$runoff frequency.

Location: Not specified.

Comments: Not evaluated.

49. Davis, L. G. 1974. Floods in Indiana: Technical manual for estimating their magnitude and frequency. U.S. Geological Survey Circular 710, 40 pp. Washington, D.C.

Abstract: Regression relationships for selected return periods of peak discharge with watershed characteristics are provided.

Classification: Statistical estimation of Q_p.

Location: Indiana.

Input Data Requirements: Model 1--area of watershed; slope of main channel; length of main channel; precipitation index; model 2--area of watershed; total relief of watershed (excluding waterfalls); drainage density; runoff coefficient (total rainfall per total runoff); model 3--area of watershed; precipitation index; model 4--area of watershed; slope of main channel; length of main channel.

Data Base for Calibration: Model 1--81 watersheds; model 2--43 watersheds; model 3--144 watersheds; model 4--20 watersheds; 10-year minimum for all models.

Limitations on Data Base: Model 1--area of watershed>200 square miles; model 2--15 square miles<area of watershed<100 square miles; model 3--area of watershed>15 square miles; model 4--Wabash and White Rivers.

Calibration Results: Standard errors for Models (1) 26-29 percent; (2) 33-37 percent; (3) 50-63 percent; (4) 9-11 percent.

Comments: None.

50. Dawdy, D. R., R. W. Lichty, and J. M. Bergmann. 1972. A rainfall-runoff simulation model for estimation of flood peaks for small drainage basins. U.S. Geological Survey Professional Paper 506-B, 28 pp. Washington, D.C.

Abstract: Paper discusses application of the USGS watershed model which uses data from a point rainfall gage and daily evaporation to predict peak flow and flood volume for a continuous period. Accuracy is limited to about 25 percent.

Classification: Multiple discrete events.

Location: Contiguous United States.

Input Data Requirements: Effect of moisture content and capillary potential at the wetting front for field-capacity conditions; factor that varies the effective value of moisture content and capillary potential as a function of soil-moisture-storage; saturated value of hydraulic conductivity; soil-moisture-storage volume at field capacity; coefficient to convert pan evaporation to potential evapotranspiration; a constant drainage rate for redistribution of soil moisture; proportion of daily rainfall that infiltrates the soil.

Data Base for Calibration: Three watersheds; see Comments.

Limitations on Data Base: Not specified.

Calibration Results: Limit of accuracy of prediction of flood peaks is about 25 percent.

Comments: Drainage basin data for watershed:

	1	2	3
Area (square miles)	9.7	5.41	6.41
Years of record	56	46	24
Mean elevation (feet)	3,600	4,150	985
Maximum peak (cubic feet per second)	5,200	1,370	7,420
Mean annual evaporation (inches)	60	39.9	53

51. DeBoer, D. W., and H. P. Johnson. 1971. Simulation of runoff from depression characterized watersheds. American Society of Agricultural Engineers Transactions 14(14):615-620.

Abstract: A simulation model is developed for use in depressional areas. Application to five events on an Iowa watershed gives a mean deviation from actual peak of 8 percent.

Classification: Multiple discrete events.

Location: Iowa.

Input Data Requirements: Not summarized.

Data Base for Calibration: Five events.

Limitations on Data Base: Not specified.

Calibration Results: Deviation from actual peaks - 8 to 29 percent; mean equals 8 percent.

Comments: Model is developed for areas characterized by glacier-caused depressions, with or without subsurface drainage tile.

52. DeCoursey, D. G. 1972. Objective regionalization of peak flow rates. Second International Symposium in Hydrology, pp. 395-405. Colorado State University, Ft. Collins.

Abstract: Sixty stations in Oklahoma are regionalized on the basis of similarity of hydrologic response using discriminant analysis and an iterative algorithm. Using canonical correlation to preserve the observed intercorrelations between peak discharges (2-, 5-, 10-, and 25-year), regression equations are developed with drainage area, mean annual precipitation, and the 2- and 100-year precipitation intensities. The results are better than with regionalization using stepwise regression.

Classification: Statistical estimation of Q_p.

Location: Oklahoma.

Input Data Requirements: Drainage area (square miles); mean annual precipitation (inches); the 2- and 100-year precipitation intensity (inches).

Data Base for Calibration: See Comments.

Limitations on Data Base: Not specified.

Calibration Results: See Comments.

Comments: Sixty stations were used for calibration; 30 stations, for verification. The results of verification and a comparison with stepwise regression are:

	Proposed technique			Stepwise regression		
Peak	R	R^2	S_e	R	R^2	S_e
2-year	0.86	0.74	$0.706E^4$	0.68	0.46	$0.100E^5$
5-year	.84	.71	$.129E^5$	.67	.45	$.182E^5$
10-year	.83	.69	$.174E^5$	.73	.53	$.221E^5$
25-year	.79	.62	$.254E^5$	.78	.61	$.236E^5$

The method preserves the observed intercorrelations between peak rates at flow.

53. Dodge, E. R. 1972. Application of hydrologic and hydraulic research to culvert selection in Montana. 116 pp. Montana State University, Bozeman.

Abstract: Regional flood frequency analysis provides regression equations for return periods from 2 to 50 years for nine geographic regions in Montana. These equations predict flood peak as the product of powers of various hydrologic watershed parameters.

Classification: Statistical estimation of Q_p.

Location: Montana.

Input Data Requirements: Area; mean annual precipitation; percent forest cover; soil index; 2-year, 24-hour precipitation.

Data Base for Calibration: 230 watersheds.

Limitations on Data Base:

Region	Range of areas (square miles)	Region	Range of areas (square miles)
1	3 to 609	6	7 to 3,174
2	0.2 to 684	7	0.1 to 1,974
3	2.3 to 2,476	8	2.7 to 2,290
4	50 to 2,623	9	0.1 to 4,464
5	0.3 to 2,554		

Calibration Results:

Region	Average percent error	Region	Average percent error
1	20-38	6	40-47
2	40-55	7	52-69
3	19-29	8	43-50
4	30-41	9	19-24
5	48-57		

Comments: None.

54. Edgerton, C. R. 1973. Handbook of design for highway surface drainage structures. 125 pp. Department of Transportation, North Carolina State Highway Commission, Raleigh.

Abstract: Method used by the North Carolina Highway Department is presented in which monographs relating discharge to drainage area and a regional factor are used for design. Corrections are made for certain factors on both rural and urban watersheds.

Classification: Statistical estimation of Q_p.

Location: North Carolina.

Input Data Requirements: Input data requirements vary with watershed conditions and may include one or more of the following: drainage area, length of watershed, frequency correction factor, percent forested, shape correction factor, and density of development.

Data Base for Calibration: Not available.

Limitations on Data Base: Area<50 square miles.

Calibration Results: None.

Comments: Adjustments must be made to all discharges in (a) areas where channelization has occurred, (b) swamp areas with large storage, and (c) areas

of significant regulation. The estimate of Q_{50} must be adjusted in urban areas and in rural areas less than 1,000 acres. The estimation of Q_{10} must be adjusted for the degree of development. Method should be used only for ungaged areas less than 50 square miles.

55. Engman, E. T., and A. S. Rogowski. 1974. A partial area model for storm flow synthesis. Water Resources Research 10(3):464-472.

Abstract: The described storm hydrograph model is based on the partial contributing area concept. It utilizes a physically based infiltration capacity distribution for computation of rainfall excess, and it incorporates two stages of kinematic routing. The model attempts to account for the natural watershed variability in terms of necessary input data and boundary and initial conditions. Data input requirements are two Manning n values, one for the channel and one for the overland flow plane, and the initial soil water content.

Classification: Single storm event: rain frequency∝runoff frequency.

Location: Pennsylvania.

Input Data Requirements: See Abstract. Additionally SCS soil data are needed.

Data Base for Calibration: One watershed.

Limitations on Data Base: Area of watershed = 144 acres, permanent pasture 50 miles each side of stream and cultivated land beyond.

Calibration Results: Graphical results provided.

Comments: None.

56. Evelyn, J. B., V. V. D. Narayana, J. P. Riley, and E. K. Israelsen. 1940. Hydrograph synthesis for watershed subzones from measured urban parameters. Report No. PRWG74-1, 51 pp. Utah Water Research Laboratory, Utah State University, Logan.

Abstract: An analog computer simulation method is developed for use on urban catchments. It is applied to a rural watershed with "reasonable" results.

Classification: Multiple discrete events.

Location: Texas.

Input Data Requirements: Rainfall intensity; total rainfall per event; interception storage; initial infiltration rate; ultimate infiltration rate; general time parameter; net precipitation; surface (depression) storage; infiltration capacity; temporary channel and valley storage; travel time through a reach; land use and slope factor.

Data Base for Calibration: One watershed.

Limitations on Data Base: Not applicable.

Calibration Results: Tabular and graphical.

Comments: The method was developed for use on urban watersheds but is applied to a rural watershed as described here.

57. Farnes, P. E. A suggested procedure for estimating peak flows. 14 pp. Soil Conservation Service, Bozeman, Mont.

Abstract: Peak discharge is found not to be a function of area for snowfed streams in Montana. It is found that the ratio of peak discharge to average annual rainfall is a function of area, the coefficient of correlation being 0.866.

Classification: Index flood estimation.

Location: Montana.

Input Data Requirements: Proportion of daily rainfall that infiltrates the soil; mean annual precipitation (rainfall in inches); area of watershed (square miles).

Data Base for Calibration: 70 watersheds.

Limitations on Data Base: Not specified.

Calibration Results: Correlation coefficient = 0.86.

Comments: The State was divided into four hydrologic regions. It is suggested that peak discharges for return periods of 10 and 50 years are multiples of the 25-year flood.

58. Federal Interagency. 1971. Red River of the North regional flood analysis (Breckinridge to International Boundary). U.S. Geological Survey, St. Paul, Minn.

Abstract: Regression analysis is used to determine flood peak for selected return periods using basin and meteorological characteristics as input.

Classification: Statistical estimation of Q_p.

Location: Minnesota-North Dakota.

Comments: Not evaluated.

59. Fields, F. K. 1975. Estimating streamflow characteristics for streams in Utah using selected channel-geometry parameters. U.S. Geological Survey Water Resources Investigations 34-74, 19 pp. Salt Lake City, Utah.

Abstract: Channel-geometry parameters are related to mean annual streamflow and the 25- and 50-year recurrence-interval flood discharges of Utah streams. Channel width and depth can be used to estimate mean annual streamflow for perennial streams with a standard error of estimate of 34 percent and ephemeral streams of 73 percent.

Classification: Statistical estimation of Q_p.

Location: Utah.

Input Data Requirements: Channel width between depositional bars.

Data Base for Calibration: 71 watersheds; 15 years minimum.

Limitations on Data Base: Not specified.

Calibration Results:

	Standard error (percent)	
Region	Q_{25}	Q_{50}
1	34	40
2	28	33
3	43	43

Comments: Channel measurements were made at 57 sites in Utah and Idaho and 14 sites in California and Nevada, with at least 15 years of record at each site. The State was separated into three regions. Region I includes stations subject to snowmelt and rainfall floods. Region II is a group of high altitude, perennial streams that generally experience snowmelt flood peaks. Region III generally experiences flooding as a result of thunderstorms.

60. Fiering, M. B. 1963. Use of correlation to improve estimates of the mean and variance. U.S. Geological Survey Professional Paper 434-C, 9 pp. Washington, D.C.

Abstract: Equations are provided for adjusting the mean and variance of a flood series using information from one or two nearby stations. Equations, which are a function of the length of the original record, the length of extension, and the coefficients of correlation, may be used to judge the relative gain in information. Also, results show that indiscriminate use of poor correlations may produce poorer estimates of moments than could be obtained from the original data.

Classification: (1) Estimation by transfer of Q_p and (2) statistical estimation of moments.

Location: Entire United States.

Input Data Requirements: Statistical moments for one or two adjacent watersheds and the correlations between the adjacent annual flood series.

Data Base for Calibration: Not specified.

Limitations on Data Base: Not specified.

Calibration Results: None.

Comments: The use of correlation to extend streamflow records may or may not improve the estimate of the mean and variance of streamflow, depending on the length of the original record, length of extension, and correlation between streamflow records.

61. Fleming, G., and D. D. Franz. 1971. Flood frequency estimating techniques for small watersheds. American Society of Civil Engineers Proceedings, Journal of the Hydraulics Division 97(HY9)1441-1460.

Abstract: The objective is to test procedures for estimating peak discharge from areas under 20 square miles. Literature is reviewed and four techniques are chosen for evaluation: (1) HSP (hydrocomp model), (2) Potter (BPR) method, (3) regional frequency (index flood), and (4) rational formula. Comparisons are given using data from various parts of the United States.

Classification: Comparison of various techniques.

Location: California, Iowa, Illinois, Maine, Missouri, Michigan, North Carolina, Pennsylvania.

Input Data Requirements: Not summarized.

Data Base for Calibration: 11 watersheds; 3 years of the record for each station (see Comments (1)).

Limitations on Data Base: Not specified.

Calibration Results: See Comments (2).

Comments: (1) Eleven watersheds were tested with records of 15-20 years and catchment area of 25 square miles or less. (2) Comparison of errors for six streams:

Method	Average error (percent)	Extreme error (percent)	Bias (percent)
HSP	17	+43	+14
Rational	299	+936	+156
Regional	40	+68	-20
Potter	33	-59	-1

62. Fletcher, J. E., A. L. Huber, F. W. Haws, and C. G. Clyde. 1976. Runoff estimates for small rural watersheds and development of sound design method. Research Report and Manual, 2 volumes. Utah Water Research Laboratory, Utah State University, Logan.

Abstract: Objectives are: (1) verify Potter's study; (2) extend Potter's method within the States considered by Potter and to the entire United States; (3) obtain details on methods used in other States for estimating peak discharges; (4) compare different methods for estimating peak; and (5) determine the record length necessary to obtain a reliable estimate of the 10-year peak flow.

Classification: Comparison of various techniques.

Location: Entire United States.

Input Data Requirements: Area of watershed; difference in elevation between culvert site and watershed divide closest to the main channel headwater; rainfall factor.

Data Base for Calibration: Approximately 956 watersheds.

Limitations on Data Base: Area of watershed $\leq$50 square miles.

Calibration Results: Standard error range 6.48 to 29.42 percent; average 14.02 percent.

Comments: The United States and Puerto Rico were divided into 24 hydrologic regions and regression analysis provided for each to obtain estimates of Q_{10}. Floods of return period (annual, 50, or 100 years) can be determined by adjusting Q_{10} by a factor for which a graph is provided.

63. Flippo, H. N., Jr. 1976. Floods in Pennsylvania: A manual for estimation of their magnitude and frequency. U.S. Geological Survey, unpublished open-file report 76-391, 55 pp. Harrisburg, Pa.

Abstract: Regression equations are presented for eight regions in the State relating peak discharge of return periods 2.33, 10, 25, 50, and 100 years to basin and climatic characteristics. In addition, discharge profiles are given for eleven major regulated streams. Standard errors range from 16 to 33 percent for areas greater than 15 square miles and 56 percent for smaller areas.

Classification: Statistical estimation of Q_p.

Location: Pennsylvania.

Input Data Requirements: Area of watershed (square miles); slope of main channel determined between 10 and 85 percent points of main channel length (feet per mile); surface storage area of ponds, lakes, and swamps (percent plus 1); precipitation index (inches) = mean annual precipitation (rainfall) - potential evapotranspiration.

Data Base for Calibration: 7-year minimum.

Limitations on Data Base: 0.70<area<3,660 square miles.

Calibration Results: See Comments.

Comments:

	Model									
	1	2	3	4	5	6A	6B	7A	7B	8
Number of stations	30	50	8	21	128	48	20	26	10	15
Standard error (percent)	19-24	26-31	16-28	27-32	25-31	22-30	45-54	24-33	46-56	26-33

64. Fogel, M. M. 1969. Effect of storm variability on runoff from small semiarid watersheds. American Society of Agricultural Engineers Transactions 12(6):808-812.

Abstract: A regression approach is used to develop a rainfall-runoff relationship for convective storms and to examine the relation between rainfall frequency and runoff frequency. Variables studied for inclusion in the relationships include the mean storm rainfall, the maximum 15-minute rainfall intensity, and the time to the mass center of the storm combined with the maximum 15-minute intensity. The explained variances range from 61 to 94 percent.

Classification: Statistical estimation of Q_p.

Location: Arizona.

Input Data Requirements: Total rainfall per event; initial infiltration rate.

Data Base for Calibration: Four subwatersheds; 13 years.

Limitations on Data Base: $0.47 \leq$ area (square miles) ≤ 7.77; $1.2 \leq$ average land slope (percent) ≤ 3.7; $0.63 \leq$ channel slope (percent) ≤ 1.20; $10{,}000 \leq$ channel length (feet) $\leq 34{,}000$.

Calibration Results: Correlation coefficients ranged from 0.78 to 0.97.

Comments: Results determined by runoff equation are approximately 10 percent less than those determined by annual series for study watersheds. A raingage network of 29 gages in an area of 20 square miles was used.

65. Fogel, M. M., I. Bogardi, and L. H. Hekman. 1975. Design of floodwater retarding structures under uncertain watershed conditions. Symposium on Hydrological Characteristics of River Basins and the Effect on These Characteristics of Better Water Management, Tokyo. International Association of Hydrological Sciences, Publication No. 117, pp. 681-690. American Geophysical Union, Washington, D.C.

Abstract: A stochastic rainfall model is developed that used Monte Carlo techniques to generate synthetic rainfall data. The rainfall data are reduced to peak discharge by the SCS technique. The resulting maximum annual peaks from 1,000 years of simulation are plotted by Gumbel extreme-value distribution to obtain frequency curves.

Classification: Multiple discrete events.

Location: Arizona.

Input Data Requirements: Initial abstractions (interception, evaporation); potential infiltration term related to runoff curve number; total rainfall per event; process of overland flow; lag time; area of watershed.

Data Base for Calibration: 28 events; 19 years.

Limitations on Data Base: Area = 20.1 square kilometers; subcatchment of the Atterbury Experimental Watershed.

Calibration Results: Correlation coefficient = 0.775 for all events.

Comments: Stratification of rainfall-runoff events was tried for use of the SCS method.

66. Fogel, M. M., L. Duckstein, and C. C. Kisiel. 1974. Modeling the hydrologic effects resulting from land modification. American Society of Agricultural Engineers Transactions 171(6):1006-1010.

Abstract: A method is presented that uses a probabilistic approach to generate rainfall data, which is converted to runoff by the SCS method. The model is intended to be used to predict the long-term hydrologic effects of land modifications.

Classification: Multiple discrete events.

Location: Arizona.

Input Data Requirements: Total rainfall per event; initial abstractions (interception, evaporation); potential infiltration term related to runoff curve number; area of watershed; duration of rainfall excess; time of concentration.

Data Base for Calibration: One watershed.

Limitations on Data Base: Area of watershed = 0.5 square mile; percent impervious = 0.

Calibration Results: Graphical.

Comments: The report is basically an application of the SCS method to urbanized watersheds, but one desert watershed was used for comparison.

67. French, R., D. H. Pilgrim, and E. M. Laurenson. 1974. Experimental examination of the rational method for small rural catchments. Paper No. 3174. Civil Engineering Transactions, 1974, pp. 95-102. The Institution of Engineers, Australia.

Abstract: This paper examines the validity of the rational method for flood peak estimation. Records from 37 catchments, each less than 250 square kilometers in area and with 10 years or more of continuous record, are analyzed to test the statistical approach to the rational method.

Classification: Empirical equations.

Location: Australia.

Comments: Not evaluated.

68. Frye, P. M., and G. S. Runner. 1969. Procedure for estimating magnitude and frequency of floods in West Virginia. 8 pp. U.S. Geological Survey and West Virginia State Roads Commission, Morgantown.

Abstract: Paper presents a method for determining peak discharge for recurrence intervals of 1.1 to 50 years for areas greater than 50 square miles in the Ohio River Basin and greater than 30 square miles in the Potomac River Basin. Two sets of curves are used, one relating mean annual flood to basin area and the other relating the desired flood to mean annual flood.

Classification: Index flood estimation.

Location: West Virginia.

Input Data Requirements: Drainage area (square miles); hydrologic region; recurrence interval (years).

Data Base for Calibration: 10-year minimum.

Limitations on Data Base: Ohio--1,400<mean annual flood (return period = 2.33 years)<200,000 cubic feet per second; Potomac--200<mean annual flood (return period = 2.33 years)<50,000 cubic feet per second.

Calibration Results: None.

Comments: Additional data have been obtained for this evaluation from USGS Water Supply Papers 1672 and 1675. Design curves are presented for both the Ohio River Basin and Potomac River Basin in West Virginia. The State was divided into numerous hydrologic regions, and curves were provided for each region.

69. Frye, P. M., and G. S. Runner. 1971. A preliminary report on small streams flood frequency in West Virginia. 9 pp. West Virginia Department of Highways and U.S. Geological Survey, Morgantown.

Abstract: A simple regression equation is presented for the Ohio River Basin of West Virginia which relates peak discharge of return period 2, 5, or 10 years to basin area. Graphical solution of the equation is presented. Standard errors range from 46 to 70 percent.

Classification: Statistical estimation of Q_p.

Location: West Virginia.

Input Data Requirements: Area of watershed (square miles).

Data Base for Calibration: 5 or 6 years.

Limitations on Data Base: 1<area<50 square miles.

Calibration Results: Standard errors of estimate, determined graphically, are 2 years--70 percent; 5 years--50 percent; 10 years--46 percent.

Comments: Graphical solution of the regression equation is presented for design. By correlation with nearby long-term data, it is suggested that Q_{25} may be determined by $Q_{25} = 1.25\ Q_{10}$, where Q_{25} = 25-year return peak discharge, and Q_{10} = 10-year return peak discharge from regression equation, but the relation cannot be checked against actual data and must be used with caution.

70. George, T. A. 1970. The Deschutes River hydrograph forecast. Proceedings of the 38th Annual Meeting of the Western Snow Conference, April 21-23, Victoria, B.C., Canada, pp. 68-73.

Abstract: Regression equations are provided for predicting water yield. A graphical analysis is used to estimate peak flows and low flows.

Classification: Statistical estimation of Q_p.

Location: Canada.

Comments: Not evaluated.

71. Golden, H. G. 1973. Preliminary flood-frequency relations for small streams in Georgia. U.S. Geological Survey, unpublished open-file report, 29 pp. Atlanta, Ga.

Abstract: Regression equations are developed using data from 102 small basins (less than 20 square miles) and 120 large basins (20 to 1,000 square miles). The mean annual flood is a function of drainage area, soil infiltration capacity index, and the 2-year, 24-hour precipitation intensity. Index ratios for return periods of 10, 25, and 50 years are provided.

Classification: Index flood estimation.

Location: Georgia.

Input Data Requirements: Area (square miles); soil infiltration capacity index; 2-year, 24-hour precipitation index (inches).

Data Base for Calibration: 202 stations.

Limitations on Data Base: Area<1,000 square miles.

Calibration Results: Standard errors (percent):

Flood region	Q_2	Q_{10}	Q_{25}	Q_{50}
1	32	40	38	41
2	33	38	45	48
3	31	38	43	37

Comments: State was divided into three regions. Data used for model calibration were collected before 1971. The index ratios for Q_{25} and Q_{50} were estimated using data for watersheds with areas from 20 to 1,000 square miles.

72. Golden, H. G., and M. Price. Flood-frequency analysis for small natural streams in Georgia. U.S. Geological Survey, unpublished open-file report 76-511, 75 pp. Atlanta, Ga.

Abstract: Regression analysis is used to determine flood peak for selected return periods using basin and meteorologic characteristics as input.

Classification: Statistical estimation of Q_p.

Location: Georgia.

Comments: Not evaluated.

73. Gray, D. M. 1961. Synthetic unit hydrographs for small watersheds. American Society of Civil Engineers Proceedings, Journal of the Hydraulics Division 87(HY4):33-54.

Abstract: A unit hydrograph method for ungaged watersheds is presented. A two-parameter gamma distribution was used to describe the unit hydrograph, the parameters being determined from the length and slope of the main channel.

Classification: Single storm event: rain frequency$\propto$runoff frequency.

Location: Illinois, Indiana, Missouri, Nebraska, Ohio, Wisconsin.

Input Data Requirements: Length of main channel (miles); slope of main channel.

Data Base for Calibration: 42 watersheds.

Limitations on Data Base: $0.23 \leq \text{area} \leq 32.64$ square miles.

Calibration Results: Not available.

Comments: None.

74. Guetzkow, L. C. 1977. Techniques for estimating magnitude and frequency of floods in Minnesota. U.S. Geological Survey Water Resources Investigations 77-31, 44 pp. St. Paul, Minn.

Abstract: Regression analysis is used to determine flood peak for selected return periods using basin and meteorological characteristics as input.

Classification: Statistical estimation of Q_p.

Location: Minnesota.

Comments: Not evaluated.

75. Hains, C. F. 1973. Floods in Alabama. U.S. Geological Survey, unpublished open-file report, Montgomery, Ala.

Abstract: Regression relationships that relate peak discharge of selected return periods to drainage area, main channel, slope, lake area, orientation of the main channel, and a geographic factor, with standard errors of 17 to 35 percent, are presented.

Classification: Statistical estimation of Q_p.

Location: Alabama.

Input Data Requirements: Two relationships are provided: (1) area of watershed; slope of channel determined between 10 and 85 percent points of main channel length; surface area of ponds, lakes, and swamps; orientation of a line through the 10 and 85 percent points of the main channel length with respect to a North-South line; factor which varies with geographic region; (2) factor which varies with geographic region; area of watershed; slope of main channel determined between 10 and 85 percent points of main channel length.

Data Base for Calibration: See Comments (1).

Limitations on Data Base: Equation 1--1 square mile$<$area of watershed$<$500; equation 2--area of watershed$>$800 square miles. See Comments (2).

Calibration Results: Standard error of estimate 17 to 35 percent.

Comments: (1) It is not clear how many data sets were used in the regression analysis; the appendix of the report gives records for 255 stations. (2) For ungaged basins, with a watershed area between 500 and 800 square miles and a ratio of $\frac{\text{length of main channel}^2}{\text{area of watershed}} < 8.0$ use equation 1; otherwise use equation 2. (3) In this study, any basin with record length of 10 years for which no extension is made is considered ungaged.

76. Hannum, Curtis H. 1976. Technique for estimating magnitude and frequency of floods in Kentucky. U.S. Geological Survey Water Resources Investigations 76-62. Lexington, Ky.

Abstract: Regression analysis is used to determine flood peak for selected return periods using basin and meteorological characteristics as input.

Classification: Statistical estimation of Q_p.

Location: Kentucky.

Comments: Not evaluated.

77. Hardison, C. H. 1969. Accuracy of streamflow characteristics. U.S. Geological Survey Professional Paper 650-D, pp. D210-D214. Washington, D.C.

Abstract: Equations are provided for evaluating the accuracy of streamflow characteristics. The standard errors of the mean and standard deviation of a flood series are a function of the standard deviation of the events and the sample size. The accuracy of the T-year event may also be evaluated. The formulas are based on the method of moments and assume a normal distribution.

Classification: Statistical estimation of moments.

Location: Entire United States.

Comments: None.

78. Hardison, C. H. 1971. Prediction error of regression estimates of streamflow characteristics at ungaged sites. U.S. Geological Survey Professional Paper 750-C, pp. C228-C236. Washington, D.C.

Abstract: The standard error of prediction with a regression of peak discharge on watershed characteristics is not necessarily equal to the standard error of estimate of the regression equation. Graphs show how the relation between average prediction error and the regression error can be evaluated for any regression. The average standard error or prediction may differ by more than 50 percent from the standard error of estimate for interstation correlations greater than 0.75 or less than 0.25.

Classification: Statistical estimation of Q_p.

Location: Entire United States.

Comments: Discusses an equation for predicting standard error of prediction.

79. Hardison, C. H. 1976. Interstation correlation of peak-flow estimates. U.S. Geological Survey Research Journal 4(2):221-222.

Abstract: Equations are given for using the correlation coefficient between annual peaks at a pair of stream-gaging stations to estimate the interstation correlation coefficient of estimated T-year peaks, computed standard deviations, and computed skew coefficients at the same pair of stations. The equations are based on statistics computed from normal distributions with built-in interstation correlation.

Classification: Statistical estimation of moments.

Location: Entire United States.

Input Data Requirements: Interstation correlation coefficient of annual peaks.

Data Base for Calibration: See Comments.

Limitations on Data Base: Valid only for positive correlation coefficients of annual peaks.

Calibration Results: None.

Comments: Equations are applicable only to samples from normal or lognormal distributions. Equations are based on simulated data, with sample sizes of 10, 25, and 50.

80. Hauth, L. D. 1974. Model synthesis in frequency analysis of Missouri floods. U.S. Geological Survey Circular 708, 14 pp. Jefferson City, Mo.

Abstract: The analysis includes three distinct phases: (1) calibrate the USGS rainfall-runoff model using data from 43 sites with areas less than 10 square miles; (2) synthesize runoff using long-term rainfall records and define flood frequency curves from the synthetic series of annual maximums; (3) develop multiple regression equations using Q_t values from the frequency curves and drainage basin characteristics. The average standard error is about 35 percent.

Classification: Statistical estimation of Q_p.

Location: Missouri.

Input Data Requirements: Area of watershed (square miles); slope of main channel determined between 10 and 85 percent points of main channel length (feet per mile).

Data Base for Calibration: 43 stations; average of 10 years continuous runoff and 18 storm hydrographs.

Limitations on Data Base: 0.14 square mile <area of watershed<8.36 square miles.

Calibration Results: Average standard error about 35 percent.

Comments: The regression equations were developed using synthetic peak discharge estimates as the criterion variable.

81. Hauth, L. D. 1974. Technique for estimating the magnitude and frequency of Missouri floods. U.S. Geological Survey, unpublished open-file report, 20 pp. Jefferson City, Mo.

Abstract: Regression equations are developed for return periods of 2, 5, 10, 25, 50, and 100 years relating channel slope and watershed area to peak discharge. The average standard error of estimate is about 35 percent.

Classification: Statistical estimation of Q_p.

Location: Missouri.

Input Data Requirements: Area of watershed (square miles); slope of main channel (feet per mile).

Data Base for Calibration: 152 watersheds.

Limitations on Data Base: $0.1 \leq$ area $\leq 14{,}000$ square miles.

Calibration Results: Standard error of estimate--38.6 percent each 2 years to 33.3 percent each 100 years.

Comments: Graphical solutions of regression equations are also provided.

82. Hawkins, R. H. 1973. Improved prediction of storm runoff in mountain watersheds. American Society of Civil Engineers, Irrigation and Drainage Division Journal 99(IR4):519-523.

Abstract: This technical note suggests that the runoff curve number (CN) as presently used is not sufficient as a measure of storm runoff in some cases. It suggests that a "K" might be better where K = f (CN, precip). An estimating procedure is not presented specifically.

Classification: Single storm event: rain frequency$\propto$runoff frequency.

Location: Not specified.

Comments: Not evaluated.

83. Hayes, G. S., and R. A. Morrill. 1970. A proposed streamflow data program for Maine. U.S. Geological Survey, unpublished open-file report, 33 pp. Augusta, Maine.

Abstract: Paper evaluates the data collection system in Maine at the time of report. Includes a regression analysis relating the mean annual flood to be expected to basin area, lake and pond area, mean basin elevation, 2-year, 24-hour rainfall intensity, mean annual precipitation, forest cover, and water content of snow on March 1.

Classification: Statistical estimation of Q_p.

Location: Maine.

Input Data Requirements: Area of watershed (square miles); surface storage area of ponds, lakes, and swamps (percent of drainage area plus 1); mean elevation of basin above sea level (thousands of feet); maximum 2-year, 24-hour rainfall (inches); mean annual precipitation (rainfall); average water equivalent of snow on March 1(inches); forest cover factor (percent of area plus 1).

Data Base for Calibration: 45 watersheds; 10-year minimum.

Limitations on Data Base: $76.2 \leq \text{area} \leq 8{,}270$ square miles.

Calibration Results: Standard error of estimate 5.1 percent.

Comments: Regression equations are also presented for estimation of standard deviation of annual discharge, mean monthly discharge for all 12 months, standard deviation of mean monthly discharge for all 12 months, low flows for 7-day duration, 2-, 10-, and 20-year recurrence, and high flows for 7-day duration, 2- and 50-year recurrence. See Morrill (reference 137) for other equations.

84. Hedman, E. R., and Kastner, W. M. 1974. Progress report on streamflow characteristics as related to channel geometry of streams in the Missouri River Basin. U.S. Geological Survey, unpublished open-file report. Lawrence, Kans.

Abstract: Regression analysis is used to determine flood peak for selected return periods using basin and meteorologic characteristics as input.

Classification: Statistical estimation of Q_p.

Location: Colorado.

Comments: Not evaluated.

85. Hedman, E. R., D. O. Moore, and R. K. Livingston. 1972. Selected streamflow characteristics as related to channel geometry of perennial streams in Colorado. U.S. Geological Survey, unpublished open-file report, 14 pp. Denver, Colo.

Abstract: Regression equations applicable in the Colorado mountain regions relate channel width and depth to mean annual runoff and to peak discharge of return periods 2, 5, 10, 25, and 50 years. Standard errors for peak discharge range from 30 to 45 percent. Split sample analyses are used for verification.

Classification: Statistical estimation of Q_p.

Location: Colorado.

Input Data Requirements: Width of channel at point of streamflow estimation; depth of channel at point of streamflow estimation.

Data Base for Calibration: 53 watersheds; 17-year minimum, 79-year maximum.

Limitations on Data Base: $13.0 \leq$ width of channel at point of streamflow estimation ≤ 89.7 feet, $0.29 \leq$ depth of channel at point of streamflow estimation $\leq$ 1.71 feet.

Calibration Results: Standard error of estimate for log transformation mean annual runoff = 18.3 percent.

Comments: Applicable for ungaged streams in the Colorado mountain region.

86. Hewlett, J. D., G. B. Cunningham, and C. A. Troendle. 1977. Predicting stormflow from small basins by the R-index method. Water Resources Bulletin 13(5). (In press.)

Abstract: A deterministic, parametric, nonlinear model is presented for predicting peak discharge as a function of the mean hydrologic response, storm rainfall, and storage capacity index; the method is valid in the eastern portion of the United States. The calibration results give a standard error of 100 percent of the mean value (26 cubic feet per second per mile).

Classification: Empirical equations.

Location: Eastern United States.

Input Data Requirements: See Comments.

Data Base for Calibration: 11 basins; 468 storm events.

Limitations on Data Base: Not specified.

Calibration Results: Standard error of estimate = 26 percent.

Comments: The mean hydrologic response (R) can be obtained from a map of the eastern portion of the United States; an equation is provided for determining the storage capacity index (S), with the value of S dependent upon storm rainfall (P) and the stormflow Q; Q is a function of R, P, and the initial flow rate I.

87. Hewlett, J. D., and J. B. Moore. 1976. Predicting stormflow and peak discharge in the Redlands District using the R-index method. Georgia Forest Research Paper No. 84, 13 pp. Georgia Forest Research Council, Macon.

Abstract: Paper discusses the R-index method, or hydrologic response. Examples are provided to illustrate the wide range of application of the method.

Classification: Empirical equations.

Location: Eastern United States.

Comments: Not evaluated.

88. Horn, D. L., and G. O. Schwab. 1963. Evaluation of rational runoff coefficients for small agricultural watersheds. American Society of Agricultural Engineers Transactions 6(3):195-201.

Abstract: Coefficients are developed for seven combinations of cover and cultural practice on 11 single crop watersheds at Coshocton, Ohio. Rational formula is evaluated with 12 other watersheds and five methods for estimating the time of concentration. Rational method is concluded to be more precise than Cook's method. More research is needed on estimating the time of concentration and evaluating the runoff coefficient.

Classification: Empirical equations.

Location: Entire United States.

Input Data Requirements: Rainfall intensity, soil moisture condition (aggregate), cover factor; rainfall intensity, area of watershed, time of concentration.

Data Base for Calibration: 11 watersheds; 19 years.

Limitations on Data Base: Rainfall intensity for time of concentration; 10 acres<area of watershed<600 acres.

Calibration Results: Not available.

Comments: None.

89. Hsu, S. W. 1970. Estimation of floods in Cyprus. Mimeographed report, 18 pp. Department of Water Development, Ministry of Agriculture and Natural Resources, Republic of Cyprus.

Abstract: An empirical method is provided for estimating peak discharge for small watersheds in Cyprus. The method is based on the area, a runoff factor, a peak reduction factor, and a climatic factor.

Classification: Empirical equations.

Location: Cyprus.

Input Data Requirements: Drainage area (acres); runoff factor; peak reduction factor; climatic factor.

Data Base for Calibration: Not specified.

Limitations on Data Base: Not specified.

Calibration Results: None.

Comments: Also required are time lag (hours) as a function of slope and length of stream. Design curves for empirical constants are also provided. This is similar in structure and intent to the empirical equation provided by Chow (see reference 28).

90. Huggins, L. F., J. R. Burney, P. S. Kundu, and E. J. Monke. 1973. Simulation of the hydrology of ungaged watersheds. Technical Report No. 38, 70 pp. Water Resources Research Center, Purdue University, Lafayette, Ind.

Abstract: A computer simulation model is presented which gives an individual storm hydrograph. Good reproduction of flood peaks is observed. Study is confined to a physical rainfall-runoff model and two experimental watersheds.

Classification: Single storm event: rain frequency $\propto$ runoff frequency.

Location: Illinois.

Input Data Requirements: Precipitation distribution; crop cover factor; maximum potential interception; depth of soil controlling infiltration; depth of surface retention; roughness coefficient; antecedent moisture content for entire basin.

Data Base for Calibration: Two experimental watersheds of 82 and 45.5 acres were studied.

Limitations on Data Base: Not specified.

Calibration Results: Graphical.

Comments: The watershed is divided into subelements by a square grid. A physical rainfall-runoff model was used for studies of overland flow.

91. Huggins, L. F., and E. J. Monke. 1968. A mathematical model for simulating the hydrologic response of a watershed. Water Resources Research 4(3)529-539.

Abstract: A general mathematical model is developed to simulate the surface runoff from watersheds. The model avoids the use of lumped parameters by delineating the watershed as a grid of small, independent elements. Application of the model to two very small watersheds indicates a need for additional research to define better the relationships for surface runoff and infiltration.

Classification: Single storm event: rain frequency$\propto$runoff frequency.

Location: Not specified.

Comments: Not evaluated.

92. Huggins, L. F., and E. J. Monke. 1970. Mathematical Simulation of hydrologic events of ungaged watersheds. Technical Report No. 14, 46 pp. Water Resources Research Center, Purdue University, Lafayette, Ind.

Abstract: A general mathematical model is developed to simulate the surface runoff from watersheds. The model avoids the use of lumped parameters by delineating the watershed as a grid of small, independent elements. Application of the model to two very small watersheds indicates a need for additional research to define better the relationships for surface runoff and infiltration.

Classification: Single storm event: rain frequency$\propto$runoff frequency.

Location: Not specified.

Comments: Not evaluated.

93. Hughes, W. C. 1977. Peak discharge frequency from rainfall information. American Society of Civil Engineers Proceedings, Journal of the Hydraulics Division 103(HY1):39-50.

Abstract: This paper proposes a method for estimating a peak discharge frequency curve for small basins where only rainfall information is available. The method involves the estimation of joint probability functions for loss rates, rainfall duration, and the temporal distribution of rainfall.

Classification: Single storm event: rain frequency$\propto$runoff frequency.

Location: Not specified.

Comments: Not evaluated.

94. Jackson, D. R. 1975. Critical review of selected methods for determining unit hydrographs. Ph.D. thesis, 333 pp. Pennsylvania State University, University Park.

Abstract: This thesis provides a comprehensive review of the literature on unit hydrograph methods and a detailed study of the least squares and McSparran's methods. The McSparran method was applied to 77 events on 16 watersheds in Pennsylvania. Two methods of solving the superpositioning equations are compared for 27 events on five small watersheds.

Classification: Single storm event: rain frequency$\propto$runoff frequency.

Location: Pennsylvania.

Comments: Not evaluated.

95. Jackson, D. R., and A. K. Karplus. 1976. Use of unit hydrograph methods to compute flood frequency. Paper presented at Second Annual Midwest Regional Meeting, American Geophysical Union. 38 pp.

Abstract: This study represents a critique of the use of unit hydrograph methods, with special emphasis on theoretical and practical problems in the use of unit hydrographs. Conclusions include: (1) the assumptions inherent in the method can lead to large differences in the magnitude of the T-year peak discharge; (2) the rainfall data are not necessarily more reliable than streamflow data; (3) the relationship between rainfall frequency and runoff frequency is at best questionable; and (4) the unit hydrograph and rainfall excess procedures are questionable.

Classification: Single storm event: rain frequency$\propto$runoff frequency.

Location: Pennsylvania.

Comments: Not evaluated.

96. Jackson, N. M., Jr. 1976. Magnitude and frequency of floods in North Carolina. U.S. Geological Survey Water Resources Investigations 76-17, 26 pp. Raleigh, N.C.

Abstract: Regression equations are developed separately for two regions of North Carolina. The equations relate peak discharge for return periods of 2, 5, 10, 25, 50, and 100 years to basin area. The average standard error of estimates ranges from 39 to 53 percent.

Classification: Statistical estimation of Q_p.

Location: North Carolina.

Input Data Requirements: Area of watershed (square miles).

Data Base for Calibration: Coastal--75 watersheds; Piedmont--182 watersheds; 10-year minimum, 78-year maximum.

Limitations on Data Base: $0.25 \leq area \leq 8,410$ square miles.

Calibration Results: Standard error of estimate for Coastal Plain is 39 to 52 percent, for Piedmont, 40 to 53 percent.

Comments: The State was divided into two regions based on the results of forward step regression, the Coastal Plain and Mountain and Piedmont. Two sets of equations are provided.

97. Jackson, T. J., R. M. Ragan, and R. P. Shubinski. 1976. Flood frequency studies on ungaged watersheds using remotely sensed data. pp. 31-41. National Symposium on Urban Hydrology, Hydraulics and Sediment Control Proceedings, University of Kentucky, Lexington.

Abstract: A technique is provided for estimating parameter values for the STORM model using satellite multispectral remote sensing (LANDSAT) of watershed characteristics. Regional relationships are presented for predicting the STORM parameters (a runoff coefficient and a depression storage coefficient) from the percent of impervious area. The results are compared with USGS regionalized prediction equations and conventional techniques for estimating the parameters.

Classification: Continuous record.

Location: Maryland and Virginia.

Comments: Not evaluated.

98. James, L. D., and A. M. Lumb. 1975. Flood hydrograph simulation for urban flood frequency analysis. Application to a watershed. pp. 181-192. National Symposium on Urban Hydrology and Sediment Control Proceedings, July 28-31, University of Kentucky, Lexington.

Abstract: The steps to follow in applying a model, UROS4, are outlined. UROS4 is used to evaluate the effects of urbanization and drainageway channelization on flood frequency. The method is applied to a 1,058-acre watershed in Georgia.

Classification: Continuous record.

Location: Georgia.

Comments: Not evaluated.

99. Jencsok. E. I. 1968. Hydrologic design for highway drainage in Arizona. 53 pp. Arizona Highway Department, Bridge Division, Phoenix.

Abstract: The publication is a design manual of the Arizona Highway Department for hydrologic design of culverts and bridges. The SCS Handbook method is specified as the design method for rural areas, with the rational method used in urban areas. The method for rural watersheds uses two different forms, depending on whether the area is less or greater than 10 square miles.

Classification: Single storm event: rain frequency$\propto$runoff frequency.

Location: Arizona.

Input Data Requirements: 60-minute rainfall intensity (inches); area of watershed; process of overland flow; rainfall duration; time of concentration.

Data Base for Calibration: Not specified.

Limitations on Data Base: Not specified.

Calibration Results: None.

Comments: Only those parts of the report pertaining to the procedure for rural watersheds are evaluated.

100. Johnson, C. G., and G. A. Laraway. 1976. Flood magnitude and frequency of small Rhode Island streams--Preliminary estimating relations. U.S. Geological Survey, unpublished open-file report, 12 pp. Providence, R. I.

Abstract: A regression equation is developed that relates a 2-year flood to basin area, mean elevation, and forest cover, giving a standard error of 46 percent. It is suggested that floods of recurrence interval 10, 25, or 50 years may be found by multiplying Q_2 by index flood ratios. Other regression equations are presented relating peak discharge for return periods of 5 and 10 years to the same basin characteristics, with standard errors of 51 and 59 percent, respectively.

Classification: Statistical estimation of Q_p.

Location: Rhode Island.

Input Data Requirements: Area of watershed; mean elevation of basin above sea level; forest cover factor.

Data Base for Calibration: 29 watersheds; 6 years.

Limitations on Data Base: $0.50 \leq \text{area} \leq 295$ square miles.

Calibration Results: Standard error of estimate for Q_2 is 46 percent, for Q_5, 51 percent, and for Q_{10}, 59 percent.

Comments: While regression equations are given for 5- and 10-year floods, it is suggested that floods of 5, 10, 25, and 50 years recurrence be determined by multiplying the Q_2 flood by factors derived by Green in "Magnitude and Frequency of Floods in the United States" (U.S. Geological Survey Water Supply Paper 1671, 260 pp., Washington, D. C., 1970). These factors were derived using watersheds of area greater than 35 square miles.

101. Johnson, C. G., and G. D. Tasker. 1974. Flood magnitude and frequency of Massachusetts streams. U.S. Geological Survey, unpublished open-file report 74-131. Boston, Mass.

Abstract: Regression equation for return periods of 2, 5, 10, 25, 50, and 100 years are developed, using area of watershed, slope of main channel determined between 10 and 85 percent points of main channel length, and mean annual precipitation (rainfall) as predictor variables.

Classification: Statistical estimation of Q_p.

Location: Massachusetts.

Input Data Requirements: Area of watershed; mean annual precipitation (rainfall); slope of main channel; soils index.

Data Base for Calibration: 92 watersheds; 7-year minimum.

Limitations on Data Base: 0.25 square mile<area<500 square miles.

Calibration Results:

Return period (years)	Standard error (percent)	Return period (years)	Standard error (percent)
2	45	25	59
5	47	50	65
10	51	100	73

Comments: The equations overestimate peak discharges in Cape Cod and Plymouth Colony due to high infiltration and storage.

102. Johnson, C. G., and G. D. Tasker. 1974. Flood magnitude and frequency of Vermont streams. U.S. Geological Survey, unpublished open-file report 74-130, 37 pp. Montpelier, Vt.

Abstract: Development of multiple regression equations for return periods of 2, 5, 10, 25, 50, and 100 years uses watershed area, pond area, 2-year, 24-hour rainfall, and average seasonal snowfall to determine peak discharge. Data from 82 stations show a standard error of estimate ranging from 39 to 59 percent for different recurrence intervals.

Classification: Statistical estimation of Q_p.

Location: Vermont.

Input Data Requirements: Area of watershed (square miles); surface area of ponds, lakes, and swamps (percent); maximum 2-year, 24-hour rainfall (inches); average seasonal rainfall (inches).

Data Base for Calibration: 82 watersheds, 7-year minimum.

Limitations on Data Base: $0.27 \leq \text{area} \leq 1{,}044$ square miles.

Calibration Results: Standard error of estimate for return periods from 2 to 100 years ranges from 39 to 59 percent.

Comments: The drainage area of 53 of the 82 stations was less than 10 square miles.

103. Johnson, M. V., and Omang, R. J. 1975. A method for estimating magnitude and frequency of floods in Montana. U.S. Geological Survey open-file report, Helena, Mont.

Abstract: Regression analysis is used to determine flood peak for selected return periods using basin and meteorologic characteristics as input.

Classification: Statistical estimation of Q_p.

Location: Montana.

Comments: Not evaluated.

104. Johnson, M. V., and R. J. Omang. 1976. A method for estimating magnitude and frequency of floods in Montana. U.S. Geological Survey, unpublished open-file report 75-650, 35 pp. Helena, Mont.

Abstract: Regression equations were developed that relate peak discharge for return periods of 2, 5, 10, 25, 50, and 100 years to basin area, main channel slope, mean annual precipitation, and a regional factor. Standard errors of estimate range from 90 to 112 percent.

Classification: Statistical estimation of Q_p.

Location: Montana.

Input Data Requirements: Area of watershed (square miles); slope of main channel determined between 10 and 85 percent points on main channel length (feet per mile); mean annual precipitation (inches of rainfall); factor that varies with geographic region.

Data Base for Calibration: 422 watersheds; 29 stations--6 to 9 years, 304 stations--10 to 24 years, 89 stations--25+ years.

Limitations on Data Base: $0.1 \leq \text{area} \leq 2,600$ square miles.

Calibration Results: Average standard error of estimate 90 to 112 percent; see Comments (2).

Comments: (1) Statewide average skew coefficient of -0.15 used for all frequency analyses. (2) Average statewide standard error of estimates ranged from 90 to 112 percent; when the State was divided into seven regions, standard errors ranged from 61 to 150 percent.

105. Johnson, M. V., R. J. Omang, and J. A. Hull. 1976. Annual peak discharge from small drainage areas in Montana. U.S. Geological Survey, unpublished open-file report, 206 pp. Helena, Mont.

Abstract: A data collection program for estimating the magnitude and frequency of floods from small drainage areas in Montana is evaluated. The data base is provided.

Classification: Not classified.

Location: Montana.

Comments: Not evaluated.

106. Jordan, P. R., and T. J. Irza. 1975. Magnitude and frequency of floods in Kansas, unregulated streams. Kansas Water Resources Board Technical Report No. 11, Topeka, Kan.

Abstract: Regression analysis is used to determine flood peak for selected return periods using basin and meteorologic characteristics as input.

Classification: Statistical estimation of Q_p.

Location: Kansas.

Comments: Not evaluated.

107. Judah, O. M., V. O. Shanholtz, and D. N. Contractor. 1975. Finite element simulation of flood hydrographs. American Society of Agricultural Engineers Transactions 18(3):518-522.

Abstract: Finite element analysis is applied to the open channel flow continuity equation to route the overload flow determined from the Stanford watershed model. Results appear to be very good for a comparison of actual and simulated storm hydrographs.

Classification: Single storm event: rain frequency $\propto$ runoff frequency.

Location: Virginia.

Input Data Requirements: Time to virtual equilibrium; cross-sectional area of channel; width of channel at point of streamflow estimation; depth of channel at point of streamflow estimation; process of overland flow; a distance in the direction of flow; general time parameter.

Data Base for Calibration: One watershed.

Limitations on Data Base: Area of watershed = 224.6 hectares with land use of 54 percent wooded and 46 percent cropped.

Calibration Results: Not summarized.

Comments: None.

108. Kresge, R. F., and T. J. Nordenson. 1955. Flood frequencies derived from river forecasting procedures. American Society of Civil Engineers Proceedings, Journal of the Hydraulics Division 81(1):1-16.

Abstract: Runoff records are extended by using a rainfall-runoff relation and the precipitation records. Good agreement is attained with the observed record.

Classification: Multiple discrete events.

Location: Ohio.

Input Data Requirements: Total rainfall per event; rainfall duration; week of year; process of overland flow; baseflow index.

Data Base for Calibration: One watershed, 37 years.

Limitations on Data Base: Not specified.

Calibration Results: None.

Comments: Unit hydrograph (12-hour) was calibrated using storms from the 11-year period, 1940-50. A baseflow vs. antecedent index relationship was calibrated using "observed discharge data for the past few years."

109. Lane, L. J., and K. G. Renard. 1972. Evaluation of a basin-wide stochastic model for ephemeral runoff from semiarid watersheds. American Society of Agricultural Engineers Transactions 15(2):280-283.

Abstract: Stochastic model is presented which generates a finite number of synthetic storm events representing the range of storms to be expected. Results are favorable when compared with actual data.

Classification: Multiple discrete events.

Location: Arizona.

Input Data Requirements: Runoff events are described using five variables. Each variable is represented by a theoretical distribution, with estimates of the parameters required as input. The runoff variables are the start of the runoff season, the number of events at the outlet per runoff season, the beginning time for each event, the interval between events, and the logarithm of volume of runoff for each event. The interval between events is represented by a negative exponential distribution, with the normal distribution being used for the other four variables.

Data Base for Calibration: 8 years, 93 events; synthetic data.

Limitations on Data Base: Not specified.

Calibration Results: Tabular information provided.

Comments: Several sets of data are generated to obtain range of storms expected. This provides a means of assessing the effects of sampling in the synthetic data.

110. Lara, O. G. 1973. Floods in Iowa: Technical manual for estimating their magnitude and frequency. Iowa Natural Resources Council Bulletin No. 11, 56 pp. Iowa City.

Abstract: Regression equations are developed for return periods of 2, 5, 10, 25, 50, and 100 years.

Classification: Statistical estimation of Q_p.

Location: Iowa.

Data Base for Calibration: 136 stations with at least 14 years of record.

Limitations on Data Base: Area must be greater than 2 square miles.

Calibration Results: Standard errors ranged from 26 to 41 percent.

Comments: Equations are not applicable to sites on the Mississippi and Missouri Rivers. The State was divided into two regions. Gaged data were fitted with the log-Pearson Type III distribution and used to obtain the peak discharge estimated (cubic feet per second).

111. Lara, O. G. 1974. Floods in Iowa: A comparative study of regional flood frequency methods. Iowa Natural Resources Council Bulletin No. 12, 63 pp. Iowa City.

Abstract: This study compares the following four regional flood frequency methods using data collected at 131 gaging stations in Iowa: (1) multiple regression relating the peak discharge for selected return periods to watershed characteristics; (2) the index-flood method; and regionalization of the parameters of the (3) log-Pearson Type III distribution, and (4) log normal distribution. On the basis of split sample tests, it was concluded that both the multiple regression approach and the regionalization of the log-Pearson Type III parameters are equally reliable. Both can be applied to ungaged areas with equal confidence, and the sample from which the estimating equations are derived is adequate.

Classification: Comparison of various techniques.

Location: Iowa.

Comments: Not evaluated.

112. Larson, C. L., and R. E. Machmeier. 1968. Peak flow and critical duration for small watersheds. American Society of Agricultural Engineers Transactions 11(2):208-213.

Abstract: A model of channel runoff is given which relates peak discharge to basin area and characteristics of surface runoff. Surface runoff must be determined by other methods. The model is applied to a synthetic watershed.

Classification: Single storm event: rain frequency$\propto$runoff frequency.

Location: Minnesota.

Input Data Requirements: Duration of surface runoff; peak runoff/surface runoff; area of watershed; process of overland flow.

Data Base for Calibration: See Comments.

Limitations on Data Base: Not specified.

Calibration Results: Not specified.

Comments: A synthetic watershed was used in analyzing the peak discharge equation. It was a 21.35-square-mile watershed made up of seven 2.75-square-mile subwatersheds with characteristics similar to those in southeastern Minnesota. Only the channel phase of runoff is modeled here (routing). The land surface phase must be modeled by other means.

113. Leclerc, G., and J. C. Schaake, Jr. 1972. Derivation of hydrologic frequency curves. Massachusetts Institute of Technology Report No. 142, 151 pp. Ralph M. Parsons Laboratory, Cambridge, Mass.

Abstract: Paper presents a simulation model that uses a stochastic rainfall model rather than runoff records as input. The rainfall is input to an infiltration model and the direct runoff is routed through the catchment to determine peak flow.

Classification: Multiple discrete events.

Location: Not specified.

Input Data Requirements: Area contributing to direct runoff; drainage density; length of main channel; slope of main channel; Manning's roughness coefficient; infiltration rate (unspecified); type of flow. All parameters are for routing segment only.

Data Base for Calibration: See Comments.

Limitations on Data Base: Not specified.

Calibration Results: Tabular and graphical.

Comments: The method uses a five-step process to arrive at frequency curves: (a) rainfall generator, (b) rainfall selector (automatically selects storms likely to produce large runoff for each year), (c) final selection of storms (manual), (d) routing model (see Input Data Requirements), (e) frequency curves. The kinematic wave equation is used for routing.

114. Leclerc, G., and J. C. Schaake, Jr. 1973. Derivation of hydrologic frequency curves from rainfall. Unpublished report, 41 pp. Department of Civil Engineering, Massachusetts Institute of Technology, Cambridge.

Abstract: A theoretical basis for deriving runoff frequency curves from rainfall is presented. Historical runoff records are not required. The method is applicable regardless of the choice of rainfall and catchment models selected.

Classification: Continuous record.

Location: Entire United States.

Input Data Requirements: See Comments.

Data Base for Calibration: Not specified.

Limitations on Data Base: Not specified.

Calibration Results: Graphical.

Comments: The purpose of this paper is not to advocate the use of any particular model of rainfall or catchment response. Rather, the purpose is to present a theoretical framework for deriving runoff frequency curves from rainfall. The required input will depend on the catchment model and rainfall generator used.

115. Lee, B. H., B. M. Reich, T. M. Rachford, and G. Aron. 1974. Flood hydrograph synthesis for rural Pennsylvania watersheds. Research on Land and Water Resources Institute Report, 72 pp. Pennsylvania State University, University Park.

Abstract: A method of synthesizing design hydrographs for drainage areas from 3 to 200 square miles in Pennsylvania is provided.

Classification: Single storm event: rain frequency $\propto$ runoff frequency.

Location: Pennsylvania and humid regions in nearby States.

Input Data Requirements: Not summarized.

Data Base for Calibration: Not summarized.

Limitations on Data Base: $3<\text{area}<200$ square miles.

Calibration Results: Graphical.

Comments: Peak discharge for a return period of 2.33 years is estimated using a regression relationship. Peaks for other return periods can be estimated from index ratios. Other variables for which prediction methods are provided include slope of baseflow separation, initial discharge, peak of surface runoff hydrograph, rise time, surface runoff volume, precipitation excess duration, initial abstraction, and potential retention.

116. Lewis, G. L. 1976. Flood insurance studies. Unpublished report for U.S. Department of Housing and Urban Development, by University of Nebraska, Lincoln.

Abstract: If a Federal or State agency has not developed a curve, the USGS regional regression equations are recommended.

Classification: Statistical estimation of Q_p.

Location: Not specified.

Comments: Not evaluated.

117. Ligon, J. T., and A. G. Law. 1972. Application of a digital hydrologic simulation model to Piedmont watersheds. Report No. 26, 38 pp. Water Resources Research Institute, Clemson University, Clemson.

Abstract: Problems in adapting the Kentucky version of the Stanford model to Piedmont watersheds are discussed. Data from two watersheds are used to calibrate and evaluate the model. Results suggest that the model could be used in design for small return periods.

Classification: Continuous record.

Location: South Carolina.

Input Data Requirements: Not summarized.

Data Base for Calibration: Two watersheds; 7 years of record.

Limitations on Data Base: Not specified.

Calibration Results: Correlation coefficient = 0.779 between simulated and recorded peak flows>10 cubic feet per second over 7-year period.

Comments: Two watersheds were studied: (1) 561-acre watershed used for calibration and (2) 44-square-mile rural watershed for verification.

118. Ligon, J. T., and A. G. Law. 1973. Application of a version of the Stanford model to a small Piedmont watershed. American Society of Agricultural Engineers Transactions 16(2):261-265.

Abstract: The Kentucky version of the Stanford watershed model IV is applied to a 561-acre research watershed at Clemson, S.C. Comparison of simulated and recorded peaks gives a correlation coefficient of 0.779.

Classification: Continuous record.

Location: South Carolina.

Input Data Requirements: 33 parameters including watershed and initial moisture parameters and monthly pan coefficient.

Data Base for Calibration: One watershed.

Limitations on Data Base: Not specified.

Calibration Results: Peak flows>10 cubic feet per second: correlation coefficient = 0.779.

Comments: None.

119. Lopez, N. C., and G. L. Dugan. 1975. Estimating peak discharges in urbanizing Hawaiian watersheds for selected rainfall frequencies. Paper presented at 23d Annual Speciality Conference, Hydraulic Engineering for Optimal Use of Water Resources, Aug. 6, 1975, Seattle, Wash.

Abstract: Paper presents modification of the SCS method which may be used to study the effect of urbanization and other land use changes on peak discharge in Hawaii.

Classification: Single storm event: rain frequency$\propto$runoff frequency.

Location: Hawaii.

Input Data Requirements: Not summarized.

Data Base for Calibration: Three watersheds: records over 30 years.

Limitations on Data Base: Not specified.

Calibration Results: Not summarized.

Comments: Testing consisted of (1) comparing results of HESL (Hawaii Environmental Simulation Laboratory) with log-Pearson Type III curve, on a 2.6-square-mile watershed with 53 years of record; (2) comparing estimates by U.S. Army Corps of Engineers method with HESL, on second watershed; and (3) comparing observed and calculated peaks, on third watershed, with differences given as delta. HESL method is a modification of SCS method with a different expression for TC.

120. Los Angeles County Flood Control District. 1971. Hydrology manual: Sections A through E, 238 pp. Hydraulic Division, Los Angeles County Flood District, Los Angeles, Calif.

Abstract: Flood estimates are made using a modification of the rational method, with time-area routing to produce a composite storm hydrograph from all subareas.

Classification: Single storm event: rain frequency$\propto$runoff frequency.

Location: Los Angeles, Calif.

Input Data Requirements: Runoff coefficients; area; rainfall intensity.

Data Base for Calibration: Not specified.

Limitations on Data Base: Not specified.

Calibration Results: None.

Comments: None.

121. Lowham, H. W. 1976. Techniques for estimating flow characteristics of Wyoming streams. U.S. Geological Survey Water Resources Investigations 76-112. Cheyenne, Wyo.

Abstract: Regression analysis is used to determine flood peak for selected return periods using basin and meteorologic characteristics as input.

Classification: Statistical estimation of Q_p.

Location: Wyoming.

Comments: Not evaluated.

122. Lumb, A. M. 1975. UROS04: Urban flood simulation model for Board of Commissioners, DeKalb County, Georgia. Part 1. Documentation and users manual. 214 pp. School of Civil Engineering, Georgia Institute of Technology, Atlanta.

Abstract: A model is developed that will route rainfall excess through an urban watershed. The Stanford watershed model is used to obtain rainfall excess. Output is an individual storm hydrograph. The model is not tested on rural watersheds but should be applicable.

Classification: Continuous record.

Location: Not specified.

Comments: The model was developed for use on urban watersheds. The Stanford watershed model was used to determine rainfall excess and the developed model (UROS04) was used for routing. The model has not been tested on any but urban watersheds (significant degree of imperviousness), at least in the literature reviewed.

123. Lumb, A. M., and L. D. James. 1975. Flood hydrograph simulation for urban flood frequency analysis: The model. pp. 169-179. National Symposium on Urban Hydrology and Sediment Control Proceedings, July 28-31, University of Kentucky, Lexington.

Abstract: The Stanford watershed model is used to generate a runoff file, and a program developed to route that runoff from an urban watershed, which may be subdivided into subareas and channel and storage segments. This model is used to simulate an annual series of flood peaks and perform a flood frequency analysis at a selected point.

Classification: Continuous record.

Location: Georgia.

Comments: Not evaluated.

124. McCain, J. F. 1974. Progress report on flood-frequency synthesis for small streams in Alabama. HPR Report No. 70, 109 pp. U.S. Geological Survey and Alabama Highway Department, Montgomery.

Abstract: Synthetic flood-frequency curves are generated for 21 small (1.28 to 15.9 square miles) stream gaging stations in Alabama using the USGS rainfall-runoff model. Peak reproduction averaged 30 percent.

Classification: Multiple discrete events.

Location: Alabama.

Input Data Requirements: 10 parameters reflecting soil moisture conditions, evaporation, and runoff timing characteristics.

Data Base for Calibration: 19 stations.

Limitations on Data Base: 1.3 square miles<area<16; 2.0 miles<length of main channel<9.5; 20 feet per mile<slope of main channel<110.

Calibration Results: Average for 19 stations: 30 percent (range: 17 to 48 percent).

Comments: Report is limited to prediction at gaged sites.

125. McCain, J. F., and R. D. Jarrett. 1976. Manual for estimating flood characteristics of natural-flow streams in Colorado. Technical Manual No. 1, 68 pp. U.S. Geological Survey and Colorado Water Conservation Board, Denver.

Abstract: Regression equations are presented that relate peak discharge of return period 10, 50, 100, and 500 years to basin characteristics. For the four hydrologic regions of the State, the average standard errors range from 24 to 65 percent. Equations are also presented for estimating depths for return periods of 10, 50, 100, and 500 years. In addition, methods are available for determining peak discharge at ungaged sites on gaged streams using a relationship based on drainage areas.

Classification: (1) Estimation by transfer of Q_p and (2) statistical estimation of Q_p.

Location: Colorado.

Comments: Not evaluated.

126. McCarthy, J. R. 1972. Conceptual analysis of rainfall and runoff data with a hybrid computer. Water Resources Research 8(4):942-955.

Abstract: A watershed is represented by a serial multistage system in which each stage employs a generalized conceptual element. The stages are initial abstraction, surface storage, translation, intermediate abstractions, channel storage, final abstractions, and outlet storage. The specific character of each stage is defined by using data from an actual watershed and a hybrid computer.

Classification: Multiple discrete events.

Location: Arizona.

Input Data Requirements: Not summarized.

Data Base for Calibration: One watershed.

Limitations on Data Base: Area of watershed = 16.3 acres; sparse vegetation except along channel; low relief; soil consolidated conglomerate with scattered clay.

Calibration Results: Actual error in peaks--0.04 inch per hour without depression storage function.

Comments: None.

127. McSparran, J. E. 1968. Design hydrographs for Pennsylvania watersheds. American Society of Civil Engineers Proceedings, Journal of the Hydraulics Division 94(HY7):937-960.

Abstract: The results of a hydrograph study for small- and medium-size watersheds are presented. Twenty-six watersheds, ranging in size from 2.4 to 210 square miles, were analyzed. Unit hydrograph parameters are related to watershed characteristics. Interflow is correlated with rainfall, runoff, and antecedent moisture conditions. The proposed method is compared with the SCS method and Snyder's synthetic unit hydrograph method, with the proposed method giving better results on six test watersheds.

Classification: Single storm event: rain frequency$\propto$runoff frequency.

Location: Pennsylvania.

Input Data Requirements: Area; length to remote point; stream slope; drainage density; forest (percent); watershed shape.

Data Base for Calibration: 26 catchments.

Limitations on Data Base: 2<area<210 square miles.

Calibration Results: Tabular and graphical.

Comments: Correlation coefficients for model parameters and watershed characteristics ranged from 0.85 to 0.95. Snyder's method tended to give hydrographs with low peaks which peaked late. The SCS method usually produced hydrographs with high peak flows which peaked early. The proposed method provided the best prediction. Snowmelt was not considered. SCS method for losses was used. Interflow is related to precipitation and runoff.

128. Matalas, N. C., and E. J. Gilroy. 1968. Some comments on regionalization in hydrologic studies. Water Resources Research 4(6):1361-1369.

Abstract: A criterion is presented for choosing between a statistical characteristic of observed flows at a site and a regionalized estimate of the characteristic. The criterion is a function of the variances of the two estimates and the interstation correlation of the stations that were used in calibrating the regionalized prediction method. An estimate of the variance at an ungaged site may be estimated and is based on the values of the basin characteristics.

Classification: Estimation by transfer of Q_p.

Location: Entire United States.

Input Data Requirements: Regionalized estimate and interstation correlation.

Data Base for Calibration: Not specified.

Limitations on Data Base: Not specified.

Calibration Results: Model not tested.

Comments: None.

129. Matalas, N. C., and B. Jacobs. 1964. A correlation procedure for augmenting hydrologic data. U.S. Geological Survey Professional Paper 434-E, 7 pp. Washington, D.C.

Abstract: A linear regression for a short and a long sequence of hydrologic events is used to lengthen the short sequence. The lengthened sequence consists of original observations and regressed values plus noise. Estimates of mean and variance are unbiased. With noise, a correlation coefficient $\geq$0.5 indicates that better results will be obtained with lengthened record than by estimates from short record. Without noise the correlation coefficient must be $\geq$0.8.

Classification: Statistical estimation of moments.

Location: Entire United States.

Input Data Requirements: Long and short records of hydrologic data.

Data Base for Calibration: Not specified.

Limitations on Data Base: Not specified.

Calibration Results: None.

Comments: None.

130. Mein, R. G., E. M. Laurenson, and T. A. McMahon. 1974. Simple nonlinear model for flood estimation. American Society of Civil Engineers Proceedings, Journal of the Hydraulics Division 100(HY11):1507-1518.

Abstract: A method is presented for routing rainfall excess through a catchment. A single watershed constant is evaluated from a stream gage somewhere in the basin. Other data needed are length and streambed slope for the reach being evaluated. Reservoir storage can be modeled.

Classification: Single storm event: rain frequency $\propto$ runoff frequency.

Location: Victoria, Australia.

Input Data Requirements: Process of overland flow; length of main channel; slope of main channel at point of streamflow estimation for each subarea of catchment.

Data Base for Calibration: Not specified.

Limitations on Data Base: Not specified.

Calibration Results: None.

Comments: None.

131. Melvin, S. W., H. P. Johnson, and C. E. Beer. 1971. Predicting surface runoff from agricultural watersheds. American Society of Agricultural Engineers Transactions 14(3):505-507.

Abstract: Horton's infiltration equation is used for predicting surface runoff, its parameters being determined from a relation with antecedent precipitation index. A regression equation is developed relating total watershed runoff to surface runoff.

Classification: Statistical estimation of Q_p.

Location: Iowa.

Input Data Requirements: Process of overland flow; infiltration capacity; final infiltration capacity.

Data Base for Calibration: 94 events.

Limitations on Data Base: $49 \leq$ area of watershed $\leq 1,440$ acres.

Calibration Results: Standard error = 0.273 inch; correlation coefficient = 0.869.

Comments: None.

132. Miller, C. F. 1968. Evaluation of runoff coefficients from small natural drainage areas. Research Report No. 14, 112 pp. Water Resources Institute, University of Kentucky, Lexington.

Abstract: In a study of 39 gaged watersheds in and near Kentucky used to compare the rational method with the results of frequency analysis, the rational method consistently underestimates the flood peak. The Stanford

watershed model is used to study the variation of the runoff coefficient with mean annual rainfall, rainfall intensity, and frequency. A set of correction factors is provided to improve the reliability of the runoff coefficient method.

Classification: Continuous record.

Location: Kentucky.

Input Data Requirements: Not summarized.

Data Base for Calibration: Not summarized.

Limitations on Data Base: Not summarized.

Calibration Results: Tabular and graphical.

Comments: The runoff coefficient is divided for purposes of individual estimation into a component describing the fraction of the falling precipitation that flows overland and a component describing the fraction of the overland flow intensity that simultaneously reaches the downstream point of interest.

133. Miller, E. M. 1971. Virginia small streams program, preliminary flood-frequency relations. U.S. Geological Survey, unpublished open-file report, 28 pp. Richmond, Va.

Abstract: Regression equations developed by Nuckels in "Virginia Streamflow Data Program Analysis" (U.S. Geological Survey, unpublished open-file report, 371 pp., Richmond, Va., 1970) are tested. Peak discharge of return periods 2, 5, and 10 years are related to variables including basin area, mean elevation, forest cover, and January temperature. In addition, index flood ratios are given for the 2-year flood to estimate the 25- and 50-year floods. Standard errors range from 43.8 to 45.6 percent for Atlantic Basins and 22.7 to 31.1 percent for Ohio Basins.

Classification: Index flood estimation.

Location: Virginia.

Input Data Requirements: Atlantic Basins--area of watershed, mean elevation of basin above sea level, forest cover factor; Ohio Basins--return period = 2, 5 years: area of watershed, forest cover factor, mean January temperature; return period = 10 years; area of watershed, forest cover factor.

Data Base for Calibration: 242 watersheds; 5-10 years with some long-term records.

Limitations on Data Base: Area<20 square miles.

Calibration Results: None.

Comments: It is suggested that Q_{25} and Q_{50} may be determined by multiplying Q_2 by an index ratio.

134. Mitchell, W. D. 1972. Model hydrographs. U.S. Geological Survey Water Supply Paper 2005, 85 pp. Washington, D.C.

Abstract: A procedure for deriving a hydrograph is presented. The two hydrograph parameters can be evaluated for ungaged areas using regression relationships involving the stream length, channel slope, and a surface-storage index.

Classification: Single storm event: rain frequency$\propto$runoff frequency.

Location Applicable: Not specified.

Input Data Requirements: Length of stream; slope (10 to 85 percent method); surface-storage index.

Data Base for Calibration: 48 years.

Limitations on Data Base: Not specified.

Calibration Results: Standard error equals 41.9 percent and correlation coefficient equals 0.939.

Comments: The procedure is applicable to both gaged and ungaged basins. For gaged locations, hydrograph parameters are estimated from observed hydrographs; for ungaged locations, regression equations may be used. Parameters consist of T, the time base of the dimensionless translation hydrograph, and k, the storage constant of the storage routing equation $S = kO$. Nonlinear models are specified but are applicable only to areas for which observed hydrographs are available.

135. Moore, D. O. 1974. Estimating flood discharges in Nevada using channel-geometry measurements. Hydrologic Report No. 1, 43 pp. State of Nevada Highway Department, Carson City.

Abstract: Empirical equations are presented for estimating a 10-year flood from channel geometry on both ephemeral and perennial streams for most of Nevada.

Classification: Empirical equations.

Location: Nevada.

Input Data Requirements: Ephemeral--depth of channel at point of streamflow estimation; width of channel at point of streamflow estimation. Perennial--width of channel at point of streamflow estimation.

Data Base for Calibration: Perennial--10 stations; ephemeral--58 stations; approximately 12 years of record.

Limitations on Data Base: $0.08 \leq$ depth of channel at point of streamflow estimation ≤ 1.31 feet. $1.5 \leq$ width of channel at point of streamflow estimation ≤ 30 feet.

Calibration Results: Standard error of estimate:

	Percent
Ephemeral:	
Southern Nevada	39
Northern Nevada	41
Perennial:	
Central Nevada	41

Comments: A graphical relation is also presented that relates the 10-year flood to an estimate of 25-year flood, but no check is possible because of lack of data. One graph is used for the entire State. Different relations were developed for ephemeral and perennial streams. For ephemeral streams the equation constants and coefficients vary for the northern and southern parts of the State. The perennial equation is applicable only in the central portion of the State. Curves are also presented which relate 10-year flood to mean annual flood for most of the State.

136. Moore, D. O. 1976. Estimating peak discharges from small drainages in Nevada according to basin areas within elevation zones. Hydrologic Report No. 3, 17 pp. State of Nevada Highway Department, Carson City.

Abstract: A method is given for estimating the 10-year peak discharge from unit peak discharges in cubic feet per second per square mile for elevation zones in increments of 1,000 feet. A nonlinear relationship is provided for estimating the 25-year peak from the 10-year peak estimate.

Classification: Statistical estimation of Q_p.

Location: Nevada.

Input Data Requirements: Elevation zones in increments of 1,000 feet.

Data Base for Calibration: 57 watersheds, 10-year minimum length of record.

Limitations on Data Base: Area<150 square miles.

Calibration Results: Standard errors of 22 and 35 percent.

Comments: The State was divided into two regions (north and south), which represent differences in the types of storms. Unit flood discharges, in cubic feet per second per square mile, are specified for elevation zones for both regions for estimating Q_{10}. A nonlinear relationship is provided for estimating the 25-year peak Q_{25} from Q_{10}. The method is not recommended for drainage areas located on the valley floor.

137. Morrill, R. A. 1975. A technique for estimating the magnitude and frequency of floods in Maine. U.S. Geological Survey, unpublished open-file report 75-292, 44 pp. Washington, D.C.

Abstract: Regression equations are determined for return periods of 2, 5, 10, 25, 50, and 100 years relating peak discharge to drainage area, main channel slope, and pond storage. Average standard errors of estimate range from 31 to 49 percent, with smaller values for larger drainage areas. A drainage area equation is provided for transferring estimates at gaged sites to ungaged sites a short distance upstream or downstream.

Classification: (1) Statistical estimation of Q_p and (2) estimation by transfer of Q_p.

Location: Maine.

Input Data Requirements: Drainage area (square miles), main channel slope (feet per mile), and area of lakes and ponds (percent of drainage area plus 1 percent).

Data Base for Calibration: 60 watersheds; 10-year minimum.

Limitations on Data Base: $0.93 \leq \text{area} \leq 8{,}270$ square miles.

Calibration Results: Standard error of estimate 31 to 49 percent for 2- to 100-year return. See Comments.

Comments: Study included 23 sites having areas less than 15 square miles. A procedure is given for estimating peaks at sites a short distance upstream or downstream from a gage. For drainage areas greater than 100 square miles the standard error of estimates ranged from 20 to 32 percent for the 2- to 100-year return periods. Map skew was used to derive log-Pearson Type III frequency curve at gaged sites. These curves were used to obtain estimate of the criterion variable.

138. Narayana, V. V. D., M. A. Sial, J. P. Riley, and E. K. Israelsen. 1970. Statistical relationships between storm and urban watershed characteristics. No. PRWG 74-2, 55 pp. Utah Water Research Laboratory, Utah State University, Logan.

Abstract: Equations for predicting peak runoff rates from small urban and rural watersheds that are based on measurable storm and watershed characteristics are provided. The technique was tested for runoff events for both urban and rural watersheds.

Classification: Statistical estimation of Q_p.

Location: See Comments.

Input Data Requirements: Area; slope; main channel length; storm duration; total rainfall; maximum 30-minute rainfall; impervious cover factor; degree of channelization.

Data Base for Calibration: See Comments.

Limitations on Data Base: Not specified.

Calibration Results: Correlation coefficients--urban, 0.914; rural, 0.890.

Comments: States from which data were used for rural watersheds are Mississippi, Wisconsin, Nebraska, Arizona, New Mexico, Georgia, North Carolina, Virginia, Ohio, Oklahoma, Texas. For urban watersheds, data from Texas and Maryland were used. Fifty rural and 20 urban watersheds were used; storm events totaled 393, with 200 from rural watersheds.

139. Nasseri, I. 1976. Regional flow frequency analysis using multi-station stochastic and deterministic models. Technical Report No. 210, 177 pp. Department of Civil Engineering, Stanford University, Stanford, Calif.

Abstract: A stochastic hourly rainfall generator is used to generate synthetic traces as input to a deterministic hydrologic model, which generates hourly streamflow sequences. The output is used to determine regional flood frequency characteristics in the Blue Ridge Mountains area of North Carolina. From a 20-year record, errors of +95 percent and -75 percent can be expected for the 100-year flood, while an error range of +20 to -25 percent results for the 10-year flood.

Classification: Continuous record.

Location: Region in Blue Ridge Mountains of North Carolina.

Input Data Requirements: Not summarized.

Data Base for Calibration: Not summarized.

Limitations on Data Base: Not specified.

Calibration Results: See Comments.

Comments: Watershed size has only a minor effect on mean percent error, and it did not have a significant effect on the selection of a frequency model. The log-Pearson Type III distribution was an appropriate model for representing the frequency curve. Long-term flood records were synthetically generated using a stochastic model for hourly rainfall generation and a deterministic model to convert the rainfall records to runoff series.

140. Neely, Brextel L., Jr. 1976. Floods in Louisiana, magnitude and frequency. 3d edition. Louisiana Department of Highways, Baton Rouge.

Abstract: Regression analysis is used to determine flood peak for selected return periods with basin and meteorological characteristics as input.

Classification: Statistical estimation of Q_p.

Location: Louisiana.

Comments: Not evaluated.

141. Neff, E. L., and P. C. Sheffer. 1959. Determination of peak discharge-frequency relationship for streams within a selected area of California. U.S. Agricultural Research Service, ARS-41-32, 20 pp. Washington, D.C.

Abstract: Two sets of regression equations are given for the Sierra Nevada region of California. The equations give the 2-year flood peak and the ratio of the 100-year flood to the 2-year flood. One set is used above 6,500 feet mean elevation and the other below 6,500 feet.

Classification: Statistical estimation of Q_p.

Location: California.

Input Data Requirements: Group I--area of watershed, mean elevation of basin above sea level, mean annual runoff; Group II--mean elevation of basin above sea level, mean annual runoff.

Data Base for Calibration: Group I--17 watersheds; Group II--7 watersheds.

Limitations on Data Base: Group I--$11 \leq \text{area} \leq 308$ square miles; Group II--$22 \leq \text{area} \leq 321$ square miles.

Calibration Results: Group I, five of seven fair or better; Group II, 15 of 17 fair or better. Group I, three stations--one fair, two poor. Group II, 10 stations--9 of 10 fair or better.

Comments: The data were broken up into two groups. Group I is those basins above, and Group II below, 6,500 feet elevation. Regression equations were developed for each group, using the same significant variables but different coefficients and constants.

142. New Zealand Ministry of Works. 1964. Provisional standard for empirical estimation of flood discharges. Third revision. Technical Memorandum No. 61. Soil Conservation and Rivers Control Council.

Abstract: An empirical formula is given for estimating peak discharge of unspecified return from a coefficient of runoff-producing characteristics, a rainfall factor, a shape factor, and catchment area. The equation is developed for use in New Zealand.

Classification: Empirical equations.

Location: New Zealand.

Input Data Requirements: Area of watershed; coefficient of runoff-producing characteristics (slope and infiltration); rainfall factor; watershed shape factor.

Data Base for Calibration: Not available.

Limitations on Data Base: Area<500 square miles.

Calibration Results: Not available.

Comments: No calibration or verification information is available in report. The paper is a presentation of a standard method to be used in New Zealand rather than a technical report. Equation is not applicable when large storage in swamps and lakes exists. Q can be determined for any storm duration; use of the time-of-concentration is recommended.

143. Orsborn, J. F., F. D. Deane, M. T. Arce, and J. P. Ahlers. 1975. Relationships of low, average, and flood flows for streams in the Pacific Northwest. 61 pp. Albrook Hydraulics Laboratory, Washington State University, Pullman.

Abstract: Peak discharges for return periods of 2 and 50 years are correlated with the 7-day, 2-year low flow and average annual flow.

Classification: Statistical estimation of Q_p.

Location: Washington, Oregon, Idaho.

Input Data Requirements: Average annual flow; 2-year, 7-day low flow.

Data Base for Calibration: 270 watersheds.

Limitations on Data Base: See Comments.

Calibration Results: See Comments (2).

Comments: (1) The three States were divided into hydrologic provinces: nine for Washington, seven for Oregon, and five for Idaho. (2) "When the results of the USGS multiple regression equations are compared to the predictions made by relating one flow to another as in this study, it is evident that the percent of error involved in using flows to predict other flows is smaller."

144. Osborn, H. B., and L. Lane. 1969. Precipitation-runoff relations for very small semiarid rangeland watersheds. Water Resources Research 5(2): 40-425.

Abstract: Article gives regression equations for total volume of runoff, peak rate of runoff, duration of runoff, and hydrograph lag-time.

Classification: Statistical estimation of Q_p.

Location: Northwest United States.

Comments: Not evaluated.

145. Osborn, H. B., and E. M. Laursen. 1973. Thunderstorm runoff in southeastern Arizona. American Society of Civil Engineers, Journal of the Hydraulics Division 99(HY7):1129-1145.

Abstract: Airmass thunderstorm rainfall produces the major floods on small (100 square miles or less) rangeland watersheds in the Southwest. The intense central volume of thunderstorm rainfall, which is represented by the maximum 30-minute depth of rainfall, is correlated with peak discharge. Data from a dense rain gage network on the ARS Walnut Gulch Experimental Watershed are used to calibrate the regression model. Upper limits for peak discharges on rangeland watersheds in the Southwest are presented.

Classification: Statistical estimation of Q_p.

Location: Arizona.

Input Data Requirements: Precipitation volumes and antecedent moisture index.

Data Base for Calibration: One watershed; 30 storm events.

Limitations on Data Base: 100 square miles $\geq$ area.

Calibration Results: See Comments.

Comments: Comparison on the 58-square-mile Walnut Creek Experimental Watershed, Arizona, using 15 years of gaged annual maximums:

Method	Peak for recurrence interval (years)			
Distribution:	10	25	50	100
Normal	9,500	12,000	13,500	15,000
Log-normal	8,000	13,000	17,000	23,000
Gumbel	8,500	12,000	14,500	17,000
Log-Gumbel	8,000	14,000	23,000	35,000
Log-Pearson Type III	7,000	11,000	15,000	20,000
SCS	7,500	11,000	14,500	18,000
USGS graphical	5,000	7,500	10,000	12,500

The more intense, longer lasting thunderstorms have a well-defined core of runoff-producing rainfall. The correlation between this core of rainfall and peak discharge improves with increasing magnitude of the core, primarily because channel abstractions do not increase at the same rate; therefore the differences in abstractions for comparable events become less important.

146. Papadakis, C. N., and H. C. Preul. 1973. Testing of methods for determination of urban runoff. American Society of Civil Engineers, Journal of the Hydraulics Division 99(HY9):1319-1335.

Abstract: A brief outline of various methods developed for the calculation of urban stormwater runoff is presented. The Chicago method, the Road Research Laboratory method, the EPA storm water management model, and the University of Cincinnati urban runoff model are tested in three urban watersheds.

Classification: Continuous record.

Location: United States.

Comments: Not evaluated.

147. Parsons, D. A. 1960. Consistent representations of rainfall and runoff magnitudes. Research Report No. 334, 76 pp. U.S. Agricultural Research Service, Washington, D.C.

Abstract: Mathematical functions for representing rainfall and runoff amounts and frequencies are provided.

Classification: Not classified.

Location: Entire United States.

Comments: Not evaluated.

148. Parsons, D. A. 1972. Representations of rainfall and runoff by the descending exponential. pp. 57-75. Mississippi Water Resources Conference Proceedings, Mississippi State University, State College.

Abstract: Generally, satisfactory representations of the distribution of magnitude of discrete rainfall and runoff events are provided by the descending exponential function.

Classification: Single storm event: rain frequency$\propto$runoff frequency.

Location: Mississippi.

Comments: Not evaluated.

149. Patterson, J. L. 1971. Floods in Arkansas, magnitude and frequency characteristics through 1968. Water Resources Circular No. 11, 21 pp. Arkansas Geological Commission, Little Rock.

Abstract: Regression equations relate physical and climatic characteristics of river basins to flood characteristics at gaged basins. The equations provide estimates of peak discharges for selected return periods from 2 years to 50 years and are applicable for drainage areas of 0.1 to 3,000 square mies. Data are from gaging stations with 5 or more years of record.

Classification: Statistical estimation of Q_p.

Location: Arkansas.

Input Data Requirements: Area (square miles); mean channel length (miles); mean elevation (feet); mean annual precipitation (inches).

Data Base for Calibration: 259 watersheds; 5-year minimum.

Limitations on Data Base: $0.1 \leq$ area $\leq 3{,}000$ square miles.

Calibration Results: See Comments (2).

Comments: (1) State is divided into two regions. (2) Region I: Area<100 square miles, peak flow = function (area, length of watershed), standard error of estimate--23 to 26 percent; area$\geq$100 square miles, peak flow = function (area, slope of main channel determined between 10 and 85 percent points of main channel length), standard error of estimate--32 to 35 percent. Region II: Area<25 square miles, peak flow = function (area, slope of main channel determined between 10 and 85 percent points of main channel length, mean elevation of basin above sea level, mean annual precipitation), standard

error of estimate--22 to 46 percent; area$\geq$25 square miles, peak flow = function (area, slope of main channel determined between 10 and 85 percent points of main channel length), mean elevation of basin above sea level, mean annual precipitation, standard error of estimate--23 to 25 percent.

150. Patterson, J. L, and W. P. Somers. 1966. Magnitude and frequency of floods in the United States: Part 9, Colorado River Basin. U.S. Geological Survey Water Supply Paper No. 1683, 475 pp. Washington, D.C.

Abstract: In addition to presenting streamflow data for the Colorado River Basin, an index flood method is developed for determining peak flows at ungaged sites. No estimates of accuracy are given. Peak discharges can be estimated for return periods of 1.1 to 50 years.

Classification: Index flood estimation.

Location: Colorado River Basin.

Input Data Requirements: Area of watershed (square miles).

Data Base for Calibration: 342 watersheds; 10-year minimum.

Limitations on Data Base: 5<area<4,000 square miles.

Calibration Results: Not specified.

Comments: Six hydrologic regions were considered in determining the multipliers for the index-flood method; 23 hydrologic areas were considered.

151. Patton, P. C., and V. R. Baker. 1976. Morphometry and floods in small drainage basins subject to diverse hydrogeomorphic controls. Water Resources Research 12(5):941-952.

Abstract: Regression equations for predicting flood peaks using geomorphic parameters are developed and applied to the following areas: central Texas, southern California, north-central Utah, Indiana, and the Appalachian Plateau.

Classification: Statistical estimation of Q_p.

Location: Texas, Utah, California, Indiana.

Comments: Not evaluated.

152. Paulhus, J. L. H., and J. F. Miller. 1957. Flood frequencies derived from rainfall data. Paper No. 1451. American Society of Civil Engineers Proceedings, Journal of the Hydraulics Division 83(HY6):1-8.

Abstract: This study shows that the rainfall data need not be from the basin for which peak discharges estimates are required, and that the data from one precipitation network can be used to synthesize streamflow data for a number of basins. The transposition of rainfall data and rainfall-runoff relations not only makes it possible to extend the streamflow record of basins without rainfall data, but greatly reduces the cost of synthesizing streamflow data. A preliminary study involving 36 basins, with each basin having at least 15 years of streamflow record, showed that a rainfall record from one network and one rainfall-runoff relation can be used to synthesize flood frequency data for a number of basins.

Classification: Single storm event: rain frequency $\propto$ runoff frequency.

Location: New Jersey, Pennsylvania, Maryland, Virginia, North Carolina, Georgia, South Carolina.

Input Data Requirements: Not summarized.

Data Base for Calibration: 36 watersheds; 50-year minimum of concurrent rainfall.

Limitations on Data Base: $2.24 < \text{area} < 521$ square miles.

Calibration Results: Tabular results presented.

Comments: Runoff records are extended by using a rainfall-runoff relationship using long-term precipitation records.

153. Pickens, J. B. 1977. Applicability of selected runoff formulas to Stark County, Ohio watersheds. M.S. thesis, 207 pp. Ohio State University, Columbus.

Abstract: Study compares six flood formulas: (1) rational equation, (2) SCS method, (3) Chow's empirical equation, (4) Bureau of Public Roads method, (5) and (6) two types of USGS regression equations. The methods are tested on 16 watersheds and subwatersheds, with areas ranging from 27 to 27,500 acres. Peak discharges are computed for return periods of 5, 10, 25, 50, and 100 years. The effect of glaciation is examined.

Classification: Comparison of various techniques.

Location: Ohio.

Comments: Not evaluated.

154. Pierce, L. B. 1968. Flood-frequency synthesis for small streams in Alabama, interim progress report. Alabama Highway Research Report No. HPR 42, 51 pp. U.S. Geological Survey, U.S. Department of Transportation, and Alabama Highway Department, Montgomery.

Abstract: A method for estimating peak discharge estimates of a specified return period is presented. The multiple discrete event-hydrograph method considers rainfall amount, rainfall duration, antecedent precipitation conditions, initial loss rate, and the effect of multiple storms. Data used in the study include 18 watersheds in Alabama, each having drainage areas from 5 to 15 square miles.

Classification: Multiple discrete events.

Location: Alabama.

Comments: Not evaluated.

155. Potter, W. D. 1961. Peak rates of runoff from small watersheds. Hydraulic Design Series No. 2, 35 pp. U.S. Bureau of Public Roads, Washington, D.C.

Abstract: The method is applicable to all areas east of the 105th meridian for determining peak flows of frequency greater than or equal to 10 years. To use the method, parameters are determined from a topographic map and isoline maps provided. The watersheds were divided into two groups according to drainage characteristics.

Classification: Statistical estimation of Q_p.

Location: United States east of 105 degrees longitude.

Input Data Requirements: Area of watershed; 10-year, 1-hour rainfall; factor which varies with geographic region.

Data Base for Calibration: Group I--52 watersheds; Group II--44 watersheds; 6 to 38 years.

Limitations on Data Base: $19<\text{area}<16{,}000$ acres.

Calibration Results: Standard error of estimate: Group I: ± 20 percent; Group II: ± 17 percent; Groups I and II: ± 18 percent.

Comments: Adjustments must be made to Q_{10} whenever the drainage characteristics are significantly different from those of the basins in Group I. The variable 10-year, 1-hour rainfall is obtained from isoline maps, which were plotted from a graphical correlation of 243 ungaged watersheds with basin area. The watersheds of Group I were chosen to be similar to these watersheds in drainage characteristics.

156. Potter, W. D., F. K. Stovicek, and D. C. Woo. 1968. Flood frequency and channel cross-section of a small natural stream. International Association of Scientific Hydrology Bulletin 13(3):66-76.

Abstract: A method is given for estimating the runoff for a recurrence interval of 10 years for an ungaged small stream. The method is currently limited to natural streams with drainage areas less than 400 square miles in the eastern United States. The method requires a curve of cross-sectional area versus depth and the measurement of the discharge at a depth determined from the area-depth curve.

Classification: Statistical estimation of Q_p.

Location: Eastern United States.

Input Data Requirements: Curve showing channel cross-sectional area versus depth.

Data Base for Calibration: Not specified.

Limitations on Data Base: Not specified.

Calibration Results: Graphical and tabular.

Comments: Method is limited to watersheds less than 400 square miles and those not subjected to regulation or human changes. In a mathematical sense, this method did not require calibration. It was tested on 99 watersheds, with each streamflow record having at least 20 years of record. The criterion for testing was the percent difference between the 10-year flow from the frequency curve and the value estimated using the area versus depth curve. About 60 percent of the watersheds were within $\pm$ 10 percent, with 93 percent within $\pm$ 20 percent. The method assumes that the frequency curve of annual maximums can be represented by two straight lines on Gumbel extreme-probability paper.

157. Randolph, W. J., and Gamble, C. R. 1977. A technique for estimating magnitude and frequency of floods in Tennessee. Tennessee Department of Transportation, Knoxville.

Abstract: Regression analysis is used to determine flood peak for selected return periods using basin and meteorologic characteristics as input.

Classification: Statistical estimation of Q_p.

Location: Tennessee.

Comments: Not evaluated.

158. Rantz, S. E. 1971. Suggested criteria for hydrologic design of storm-drainage facilities in the San Francisco Bay Region, California. U.S. Geological Survey, unpublished open-file report, 69 pp. Menlo Park, Calif.

Abstract: A comparison of regression estimation, the rational method, unit hydrograph, and simulation is provided, with a quantitative comparison between regression and unit hydrograph methods.

Classification: Comparison of various techniques.

Location: San Francisco Bay Area.

Input Data Requirements: Area (square miles); mean annual precipitation (inches).

Data Base for Calibration: 40 watersheds; 10-year minimum.

Limitations on Data Base: 0.2<area<196 square miles; 13<mean annual precipitation (rainfall)<60 inches.

Calibration Results:

	Return period (years)				
	2	5	10	25	50
Standard error (percent)	54	41	40	42	46

Comments: None.

159. Rao, G. N. S., J. R. Assenzo, and J. F. Harp. 1966. Estimating peak rates of runoff and design hydrographs from rainfall in the State of Oklahoma. Journal of Hydrology 4(2):141-170.

Abstract: Paper provides regression equations relating three hydrograph parameters (peak rate of runoff, total runoff, and the time from the center of mass of the hydrograph to the runoff peak) to average 30-minute rainfall intensity, main channel length, and length from center of basin to outlet. Computed hydrograph parameters are used to define a hydrograph having the log-Pearson Type III density function.

Classification: Single storm event: rain frequency $\propto$ runoff frequency.

Location: Oklahoma.

Input Data Requirements: 30-minute rainfall intensity for designated frequency; time of concentration; infiltration capacity; main channel length; length from center of basin to outlet.

Data Base for Calibration: 70 storms.

Limitations on Data Base: Not specified.

Calibration Results: Correlation coefficients of 0.78, 0.85, and 0.64 for the three regression equations.

Comments: At least 80 percent of the estimates of peak rates did not depart from observed values by more than 30 percent (for hydrographs used in calibrating the regression equations). Equations are limited to drainage areas less than 5 square miles. A brief literature review of unit hydrograph methods is included.

160. Reich, B. M. 1960. Annotated bibliography and comments on the estimation of flood peaks from small watersheds. Technical Report CER60BMR52, 66 pp. Civil Engineering Department, Colorado State University, Fort Collins.

Abstract: Some 180 publications were reviewed for information of value in the estimation of peak runoff from small watersheds (approximately 200 acres to 3 square miles). Their contents are abstracted with emphasis on material pertinent to design methods. They are also classified according to 16 subject headings.

Classification: Not classified.

Location: Not specified.

Comments: Not evaluated.

161. Reich, B. M. 1968. Predicting high flows from small watersheds. Information Report No. 55, 72 pp. Institute for Research on Land and Water Resources, Pennsylvania State University, University Park.

Abstract: The paper presents a warning against some of the common assumptions made in regression analysis of flood events. It shows that return period of the flood is generally far different from that of the rainfall. Also, it shows that additional data from watersheds of diverse hydrologic features reduce correlation despite the enhanced sample size.

Classification: Not classified.

Location: Not specified.

Comments: Not evaluated.

162. Reich, B. M. 1968. Rapid flood-peak determination on small watersheds. American Society of Agricultural Engineers Transactions 11(2):291-295.

Abstract: Paper presents a method of peak flow prediction that uses rainfall, time of concentration, and infiltration capacity with design charts. The charts given are thought to be applicable to most of the 48 contiguous States.

Classification: Statistical estimation of Q_p.

Location: Entire United States.

Input Data Requirements: 30-minute rainfall intensity for designated frequency; time of concentration; infiltration capacity.

Data Base for Calibration: 47 watersheds.

Limitations on Data Base: Not specified.

Calibration Results: None.

Comments: Certain areas of Washington, Oregon, California, Nevada, Idaho, and Montana are inapplicable. Original study was by Reich (see reference 160), Colorado State University; also discussed in Journal of Hydrology 3:231-253.

163. Reich, B. M. 1971. Runoff estimates for small rural watersheds. 135 pp. Civil Engineering Department, Pennsylvania State University, University Park.

Abstract: A qualitative assessment of methods that are frequently used in flood estimation is presented. A simplified unit hydrograph procedure is presented. Regional flood frequency methods are compared.

Classification: Single storm event: rain frequency$\propto$runoff frequency.

Location: Pennsylvania.

Input Data Requirements: Antecedent precipitation index; total rainfall per event; slope of main channel at gage or point of streamflow estimation; SCS runoff curve number; temperature (unspecified).

Data Base for Calibration: 182 watersheds.

Limitations on Data Base: 10-year, 1-hour rainfall (total rainfall per event) $>$ 3.0 inches.

Calibration Results: Coefficient of determination = 0.84, summer; coefficient of determination = 0.81, winter.

Comments: Separate prediction equations were developed for summer and winter.

164. Reich, B. M., and L. A. Hiemstra. 1965. Tacitly maximized small watershed flood estimates. American Society of Civil Engineers Proceedings, Journal of the Hydraulics Division 91(HY3):217-245.

Abstract: A method is presented that estimates the maximum expected peak and associated volume, considering stream length, basin relief, vegetation, 30-minute rainfall volume, and an indicator of infiltration. The average of recorded peaks is 14 percent greater than those computed.

Classification: Statistical estimation of Q_p.

Location: All contiguous United States, except parts of California, Oregon, Washington, Idaho, Nevada.

Input Data Requirements: 30-minute rainfall; indicator of infiltration capacity (high, medium, low); time of concentration.

Data Base for Calibration: 29 watersheds; 83 floods from 50 storms.

Limitations on Data Base: 30-minute rainfall<5 inches; $130 \leq \text{area} \leq 4{,}380$ acres.

Calibration Results: The average of recorded peaks was 14 percent greater than the average of computed peaks.

Comments: The method can also predict the total volume of runoff. Stratification of data is discussed.

165. Reich, B. M., and D. R. Jackson. 1971. Flood prediction methods for Pennsylvania highway crossings. 192 pp. Civil Engineering Department, Pennsylvania State University, University Park.

Abstract: Report describes a method called PSU III that uses regression to obtain mean annual flood from basin area and 2.33-year, 24-hour rainfall. Mean annual flood is then related to floods of 10, 25, 50, 100, 200, 500, and 1,000 years by an index method. A comparison is made between this method and five others commonly used--the Potter method, the SCS method, the rational method, and two other methods developed at Pennsylvania State University. The State is divided into three zones--(1) Valley and Ridge, (2) Appalachian Plateau, and (3) Piedmont.

Classification: (1) Index flood method and (2) comparison of various techniques.

Location: Pennsylvania.

Input Data Requirements: Area of watershed; 2.33-year, 24-hour rainfall.

Data Base for Calibration: Valley and Ridge: 38 watersheds; Appalachian Plateau: 66 watersheds; Piedmont: 29 watersheds.

Limitations on Data Base: Valley and Ridge: $3.1 \leq \text{area} \leq 200$ square miles; Appalachian Plateau: $2.4 \leq \text{area} \leq 192$ square miles; Piedmont: $2.0 \leq \text{area} \leq 133$ square miles; $2.99 \leq$ 2.33-year, 24-hour rainfall ≤ 3.5 inches.

Calibration Results: Valley and Ridge: correlation coefficient = 0.93; Appalachian Plateau: correlation coefficient = 0.93; Piedmont: correlation coefficient = 0.97.

Comments: None.

166. Reich, B. M., V. P. King, and E. L. White. 1971. Flood peak frequency design manual-PSU III. 6 pp. Civil Engineering Department, Pennsylvania State University, University Park.

Abstract: The index-flood method is outlined for use in small drainage areas in Pennsylvania. Index ratios are provided for return periods of 10, 25, 50, 100, 200, 500, and 1,000 years. The index flood (2.33 years) is a function of the drainage area.

Classification: Index flood estimation.

Location: Pennsylvania.

Comments: Not evaluated.

167. Reich, B. M., and D. A. Wolf. 1973. The triangle as a tentative unit hydrograph. Paper presented at 1st World Congress of International Association for Water Resources, Chicago, Ill.

Abstract: A triangular unit hydrograph is used to represent the watershed response. Ninety percent of the variation in peak rates of discharge for 1-hour unit hydrographs from watersheds of 4 through 120 square miles can be accounted for by an equation using two predictor variables.

Classification: Single storm event: rain frequency $\propto$ runoff frequency.

Location: Pennsylvania.

Input Data Requirements: Base time of hydrograph; slope of main channel.

Data Base for Calibration: 17 watersheds; 69 flood hydrographs.

Limitations on Data Base: Area<120 square miles.

Calibration Results: $\pm$ 20 percent.

Comments: Article gives a "cook-book" procedure for determining peak flow. No detailed information is given for analysis of calibration or testing data.

168. Resource Analysis, Inc. 1975. Rainfall analysis and generation model: Description and theoretical background. 62 pp. Cambridge, Mass.

Abstract: Paper discusses the development and use of rainfall analysis and generation models for analyzing the historic rainfall record at a site, the generation of long-term synthetic records, and the creation of synthetic storms for hydrologic-hydraulic analysis. Runoff frequency estimates may be obtained using a rainfall-runoff model based on a linear-routing concept and an empirical storm response index.

Classification: Multiple discrete events.

Location: Not specified.

Input Data Requirements: Storm response index = peak outflow from five linear reservoirs connected in series.

Data Base for Calibration: Not summarized.

Limitations on Data Base: Not summarized.

Calibration Results: Graphical.

Comments: Additional data requirements include average monthly precipitation; the probability for each month of no rainfall in the catchment on any day; the probability for each month of the ground being frozen; typical infiltration conditions; probability distributions of storm intervals, durations, and depths.

169. Richardson, C. W., R. W. Baird, and E. T. Smerdon. 1969. Computer methods for predicting storm hydrographs based on antecedent soil moisture. American Society of Agricultural Engineers Transactions 12(2):266-269.

Abstract: General form of equation is presented for determining retention of rainfall by soil (infiltration). Uses a soil moisture accounting procedure and Stanford model to route streamflow.

Classification: Continuous record.

Location: Entire United States.

Input Data Requirements: General time parameter; antecedent retention index at start of runoff; antecedent retention index at start of rainfall. Additional input requirements not summarized.

Data Base for Calibration: 28 events; 10 years.

Limitations on Data Base: Area of watershed = 20.8 acres.

Calibration Results: Not specified.

Comments: The equation developed predicts the retention of rainfall due to infiltration. Precipitation excess is determined by subtracting retention from precipitation (total rainfall per event). The equation developed is used for continuous soil-moisture accounting and precipitation excess is routed.

170. Riggs, H. C. 1974. Flash flood potential from channel measurements. Symposium on Flash Floods, International Association of Hydrological Sciences Publication No. 112, pp. 52-56. Paris.

Abstract: Transfer method determines peak discharge at ungaged sites utilizing the channel dimensions and a relation between flood peak and channel dimensions at a gaged site.

Classification: Estimation by transfer of Q_p.

Location: Northwest United States, Kentucky, Colorado, Utah, Wyoming, Arkansas, Kansas, Nevada.

Input Data Requirements: Width of channel at point of streamflow estimation.

Data Base for Calibration: See Comments.

Limitations on Data Base: 1<width of channel at point of streamflow estimation<500 meters.

Calibration Results: Quantitative index not given; plots show data points as well as "best fit" line (not defined).

Comments: No information on the data used is given other than graphical plots. Method is best applicable in semiarid regions according to report.

171. Riggs, H. C. 1976. A simplified slope-area method for estimating flood discharges in natural channels. U.S. Geological Survey Research Journal 4(3):285-291.

Abstract: A simplified method estimates peak discharge from high water marks using the slope of the water surface and cross-sectional area as input.

Classification: Estimation by transfer of Q_p.

Location: United States but primarily northwestern United States.

Input Data Requirements: Channel cross-sectional area; water surface slope.

Data Base for Calibration: 30 stations.

Limitations on Data Base: Not specified.

Calibration Results: Standard error, about 20 percent.

Comments: None.

172. Riggs, H. C., and W. A. Harenberg. 1976. Flood characteristics of streams in Owyhee County, Idaho. U.S. Geological Survey Water Resources Investigations 76-88, 14 pp. Boise, Idaho.

Abstract: A method is provided for estimating the 10-year peak discharge from estimates of the whole channel section width.

Classification: Statistical estimation of Q_p.

Location: Owyhee County, Idaho.

Input Data Requirements: Whole channel section width.

Data Base for Calibration: 25 watersheds.

Limitations on Data Base: Not specified.

Calibration Results: See Comments (1).

Comments: (1) Variability in measuring width among seven experienced individuals would result in a standard error of the computed 10-year flood of about 30 percent. (2) A relationship is also provided for computing whole channel width from active channel width.

173. Riley, J. P., V. J. Rogers, and G. V. Shih. 1974. Hydrologic model studies of the Mt. Olympus Cove Area of Salt Lake County. 91 pp. College of Engineering, Utah State University, Water Resources Laboratory, Logan.

Abstract: This report describes the model development process and discusses the application of the models to three source areas, each having a drainage area less than 5 square miles. Runoff from short-term, high-intensity, convective storms is emphasized. The hydrologic response is found to be particularly sensitive to the magnitude of the runoff-producing event and to the soil moisture conditions immediately preceding the storm event. Graphical methods are presented for estimating peak runoff rates and flood damages.

Classification: Continuous event.

Location: Utah.

Input Data Requirements: Not summarized.

Data Base for Calibration: Three watersheds.

Limitations on Data Base: Drainage area$\leq$5 square miles.

Calibration Results: Graphical and tabular.

Comments: None.

174. Robinson, F. L. 1961. Floods in New York, magnitude and frequency. U.S. Geological Survey Circular 454, 10 pp. Washington, D.C.

Abstract: A technique is presented for estimating peak discharge for most of New York using design charts. The index flood method involves a graphical relationship between mean annual flood and drainage area and another relating flood peaks of other recurrence intervals to the mean annual flood.

Classification: Index flood estimation.

Location: New York.

Input Data Requirements: Surface area of ponds, lakes, and swamps; slope of main channel.

Data Base for Calibration: 128 watersheds; 5-year minimum, 46-year maximum.

Limitations on Data Base: 22.0$\leq$area$\leq$4,780 square miles.

Calibration Results: None.

Comments: Author indicates that the method is not applicable for drainage areas less than 10 square miles (note that this is beyond the range of data used in calibration) or where flood peaks are affected by human regulation. The State was divided into seven regions.

175. Robinson, F. L., and T. T. Williams. 1968. Frequency of peak flows predicted from rainfall frequencies. 114 pp. Department of Civil Engineering and Engineering Mechanics, Montana State University, Bozeman.

Abstract: A method called rainfall-discharge induction is developed for estimating peak flow for a return period of 50 years. Required input includes short-term runoff and precipitation records. Floods of other return periods may also be estimated.

Classification: Index flood estimation.

Location: Montana.

Input Data Requirements: Mean annual flood (return period = 2.33 years); rainfall intensity ratio = 50-year maximum true interval rainfall intensity/ mean annual true interval rainfall intensity; rainfall-discharge recurrence factor; rain-snow-baseflow interaction ratio.

Data Base for Calibration: 12 watersheds; 11 to 36 years.

Limitations on Data Base: $31.4 \leq \text{area} \leq 684$ square miles.

Calibration Results: Graphical and tabular.

Comments: Test watersheds: $0.14 \leq \text{area} \leq 1{,}805$ square miles, record = 7 to 42 years. The mean annual flood (return period = 2.33 years) is determined by averaging the annual peaks of the short record. Floods of other than 50-year frequency can be determined by plotting Q_{50} and mean annual flood ($Q_{2.33}$) on Gumbel extreme-value probability paper and drawing a straight line through the points. This is an index flood method in which the ratios of Q_{50} to Q_{MAF} depend on three parameters.

176. Robinson, F. L., and T. T. Williams. 1972. Floods predicted from rainfall frequencies. American Society of Civil Engineers Proceedings, Journal of the Hydraulics Division 98(HY10):1773-1787.

Abstract: A method is developed to predict floods on small Montana watersheds. The method uses mean annual flood, which is determined from short streamflow records, and three factors relating the frequency distribution of rainfall intensities to the frequency distribution of peak annual flows.

Classification: Index flood estimation.

Location: Eastern Montana.

Input Data Requirements: Rainfall intensity ratio = 50-year maximum true interval rainfall intensity/mean annual true interval rainfall intensity; rainfall-discharge recurrence factor; rain-snow-baseflow interaction ratio.

Data Base for Calibration: 11 watersheds, 44 rain gages; maximum yearly.

Limitations on Data Base: Not specified.

Calibration Results: Graphical and tabular.

Comments: Prediction accuracy is poor for short record periods. Method is not applicable to watersheds where yearly peak flow is primarily the result of snowmelt.

177. Rossmiller, R. L., and M. D. Dougal. 1974. A computerized method for the hydrologic design of culverts. 242 pp. Engineering Research Institute, Iowa State University, Ames.

Abstract: The SCS method of predicting peak discharge is used in a computer program for culvert design. Upstream channel and valley storage is accounted for to reduce the peak.

Classification: Single storm event: rain frequency$\propto$runoff frequency.

Location: Iowa.

Input Data Requirements: Input requirements are grouped into four general types--hydrologic data, stage-storage data, identification data, and hydraulic data.

Data Base for Calibration: Not summarized.

Limitations on Data Base: Not summarized.

Calibration Results: Graphical and tabular.

Comments: Model can be used in other areas with adjustments. Whenever the value of peak discharge determined by the SCS method is less than that from the Iowa State Highway Commission method, the ISHC value is used. Program has the capability to design the culvert best suited to the computed peak discharge.

178. Saah, A. D., R. Talley, and W. J. Sancher, Jr. 1967. Development of regional regression equations for solution of certain hydrologic problems in and adjacent to Santa Clara County. 91 pp. Santa Clara Valley Water District, San Jose, Calif.

Abstract: Regression equations for determining peak discharge and volumes for selected durations are presented for use in Santa Clara County. The equations predict the mean and standard deviation; the skew is determined using weighted regional estimates.

Classification: Statistical estimation of moments.

Location: Santa Clara County and vicinity.

Input Data Requirements: Area (square miles); mean annual precipitation (inches); and a basin factor.

Data Base for Calibration: 20 stations.

Limitations on Data Base: Not specified.

Calibration Results:

Statistic	Correlation coefficient	Standard error of estimate
$\overline{X}$	0.817	0.210
S	.502	.065

Comments: The mean and standard deviations of the logarithms were regressed on watershed and climatological characteristics. The skew coefficient was determined using the procedure in "Guidelines for Determining Flood Flow Frequency" (Bulletin 17, Hydrology Committee, U.S. Water Resources Council, Washington, D. C., 1976). A regional skew of -0.6 was selected from analysis of station data.

179. Sauer, V. B. 1974. Flood characteristics of Oklahoma streams. U.S. Geological Survey Water Resources Investigations 52-73, 46 pp. Oklahoma City.

Abstract: Regression equations are developed for return periods of 2, 5, 10, 25, 50, and 100 years relating peak discharge to watershed area, channel slope, and mean annual precipitation. Report also presents relationships for gaged basins and individual frequency relationships for some main stem streams and a compilation of flood data through 1971. For streams draining 100 square miles or more, standard errors of 40 to 50 percent were found.

Classification: Statistical estimation of Q_p.

Location: Oklahoma.

Input Data Requirements: Area of watershed (square miles); slope of main channel determined between 10 and 85 percent points of main channel length (feet per mile); mean annual precipitation (inches of rainfall).

Data Base for Calibration: 119 watersheds; 8-year minimum, 17-year mean.

Limitations on Data Base: Area<2,500 square miles.

Calibration Results: Standard errors of regression (percent):

Area (square miles)	Return period (years)					
	2	5	10	25	50	100
<100	67	60	64	-	-	-
>100	43	41	41	40	43	50

Comments: Magnitude of error may be large for large recurrence intervals on basins of less than 100 square miles. The predicting equations for $Q_{25, 50, 100}$ were determined from the regression equations for $Q_{2, 5, 10}$ by defining relationships between the different peaks from the data and substituting the known equations for $Q_{2, 5, 10}$.

180. Schaake, J. C., Jr., J. C. Geyer, and J. W. Knapp. 1967. Experimental examination of the rational method. American Society of Civil Engineers Proceedings, Journal of the Hydraulics Division 93(HY6):353-370.

Abstract: Rainfall and runoff data collected in Baltimore, Md., from 20 gaged urban areas ranging in size up to 150 acres are used in a study of the rational method. The results suggest that the assumption that rain frequency equals runoff frequency may be nearly correct when an appropriate C value has been selected. Presently used values of C are not adequately based on measurements of rainfall and runoff in urban areas, so large errors can occur when the rational method is used. A test of user reproducibility is provided, with errors ranging from -46 to +61 percent.

Classification: Empirical equations.

Location: Maryland.

Comments: Not evaluated.

181. Schermerhorn, V., and M. Barton. 1968. A method for integrating snow survey and precipitation data. 6 pp. Proceedings of the 36th Annual Western Snow Conference, Lake Tahoe, Nev.

Abstract: Study suggests that models which combine snow course and winter precipitation measurements into a single winter index provide better estimates than either variable alone. Multiple regression equations are developed for three sites to examine the accuracy of the combined index. The model is used to predict water yield.

Classification: Statistical estimation of Q_p.

Location: Washington, Oregon, Idaho.

Comments: Not evaluated.

182. Scott, A. G. 1971. Preliminary flood frequency relations and summary of maximum discharges in New Mexico. U.S. Geological Survey, unpublished open-file report, 76 pp. Albuquerque, N. Mex.

Abstract: Regression equations are developed for three regions of New Mexico. The equations relate peak discharges of return periods of 2, 5, 10, 25, and 50 years to basin and climatic characteristics and give standard errors up to 164 percent.

Classification: Statistical estimation of Q_p.

Location: New Mexico.

Input Data Requirements: Region I--area of watershed; slope of main channel determined between 10 and 85 percent points of main channel length; maximum 2-year, 24-hour rainfall; mean minimum January temperature; Region II--area of watershed; watershed shape factor; mean minimum January temperature; Region III--area of watershed; mean elevation of basin above sea level; surface area of ponds, lakes, and swamps; May-September precipitation; maximum 2-year, 24-hour rainfall; mean minimum January temperature.

Data Base for Calibration: Region I--56; Region II--33; Region III--74; 19-year mean, range is 8 to 51 years of record.

Limitations on Data Base: Region I--0.33≤area of watershed≤558 square miles; 22≤slope of main channel determined between 10 and 85 percent points of main channel length≤862 feet per mile; 1.18 inches≤maximum 2-year, 24-hour rainfall≤2.35; 2.0≤mean minimum January temperature 28 degrees Fahrenheit; Region II--0.20≤area of watershed≤1,370 square miles; 18≤mean minimum January temperature≤28 degrees Fahrenheit; Region III--0.16≤area of watershed≤1,390 square miles; 4.09 feet≤mean elevation of basin above sea level≤9.5; 0≤ surface area of ponds, lakes, and swamps≤3.49 percent; 0.10≤mean minimum January temperature≤28 degrees Fahrenheit.

Calibration Results: Average standard error of estimate (percent):

	Return period (years)				
Region	2	5	10	25	50
I	94	88	88	92	98
II	164	120	116	112	124
III	86	83	82	72	74

Comments: The State was divided into three regions and equations were developed for each.

183. Scott, A. G., and J. L. Kunkler. 1976. Flood discharges of streams in New Mexico as related to channel geometry. U.S. Geological Survey, unpublished open-file report, Albuquerque, N. Mex.

Abstract: Regression analysis is used to determine flood peak for selected return periods using basin and meteorologic characteristics as input.

Classification: Statistical estimation of Q_p.

Location: New Mexico.

Comments: Not evaluated.

184. Shanholtz, V. O., and J. H. Lillard. 1971. Simulations of watershed hydrology on agricultural watersheds in Virginia with the Stanford model. 47 pp. Department of Agricultural Engineering, Virginia Polytechnic Institute and State University, Blacksburg.

Abstract: The Stanford model is calibrated and tested using two small watersheds, with 5 years of record used for calibration and 5 years for testing. Water yield estimates are reasonably good and instantaneous peak estimates erratic; maximum peak estimates for the water year have acceptable accuracy.

Classification: Continuous record.

Location: Virginia.

Input Data Requirements: Not summarized.

Data Base for Calibration: Two small watersheds with 10 years of data each.

Limitations on Data Base: Not summarized.

Calibration Results: Graphical and tabular.

Comments: A sensitivity analysis, which involved the perturbation of individual parameters, was also performed. An error analysis was also done to determine the effect of errors in precipitation and potential evapotranspiration data.

185. Singh, K. P. 1976. Unit hydrographs--a comparative study. Water Resources Bulletin 12(2):381-392.

Abstract: Unit hydrographs derived by using two methods, linear programing and least squares, are compared. Test data comprise rainfall and runoff information from four storms over the North Branch, Potomac River, near Cumberland, Md. The unit hydrographs derived with the two methods are practically the same for storm events 2 and 3 but differ somewhat for storm events 1 and 4.

Classification: Single storm event: rain frequency$\propto$runoff frequency.

Location: Upper Branch, Potomac River, near Cumberland, Md.

Input Data Requirements: Not summarized.

Data Base for Calibration: Four storm events.

Limitations on Data Base: Not specified.

Calibration Results: Not summarized.

Comments: Linear programing uses the minimum sum of the absolute deviations as the criterion function, while least squares uses the minumum sum of the squares of the deviations.

186. Sinha, L. K., and L. E. Lindahl. 1971. An operational watershed model: General considerations, purposes, and progress. American Society of Agricultural Engineers Transactions 14(4):688-691.

Abstract: Paper presents a continuous simulation program that accounts for infiltration, evapotranspiration, evaporation, and percolation losses; recovers the infiltration loss; and routes overland and groundwater flow through the channel-reservoir system to give a continuous hydrograph. Results for two time periods on a single watershed are called "excellent."

Classification: Continuous record.

Location: Florida.

Input Data Requirements: Surface penetration index; soil-moisture storage; ultimate infiltration rate; total amount of gravitational water that could exist in a soil profile of selected depth; depth to water table; maximum depth to water table at which depth to water table will cease to contribute to evaporation; evapotranspiration; Manning's roughness coefficient; time increment for hydrologic simulation; overall growth index for existing vegetation; total number of reservoirs (for routing).

Data Base for Calibration: Not summarized.

Limitations on Data Base: Not summarized.

Calibration Results: Not summarized.

Comments: The model described here is a submodel of an overall watershed model for the Central and Southern Florida Flood Control District. At the time of the article the model was still in the developmental stage.

187. Sittner, W. T., C. E. Schauss, and J. C. Monro. 1969. Continuous hydrograph synthesis with an API-type hydrologic model. Water Resources Research 5(5):1007-1022.

Abstract: "The model consists of four basic parts: a relation for computing ground-water recession, a method of computing the ground-water flow hydrograph as a function of the direct runoff hydrograph, an API-type rainfall-runoff relation, and a unit hydrograph."

Classification: Continuous record.

Location: North Carolina and Maryland.

Input Data Requirements: Recurrence interval; antecedent precipitation index; others not summarized.

Data Base for Calibration: Two watersheds.

Limitations on Data Base: North Carolina--French Broad River; area of watershed = 68 square miles; mean annual precipitation (rainfall) = 70-80 inches. Maryland--Monocacy River; area of watershed = 817 square miles; mean annual precipitation (rainfall) = 40-45 inches.

Calibration Results: Not specified.

Comments: None.

188. Smith, R. E., and D. L. Chery, Jr. 1973. Rainfall excess model from soil water flow theory. American Society of Civil Engineers Proceedings, Journal of the Hydraulics Division 99(HY9):1337-1351.

Abstract: An infiltration model is developed for use on small areas in the semiarid and arid Southwest. All parameters can be estimated using data from one type-F infiltrometer experiment. The model, called SEQM, is compared with Holton's INFIL on a small experimental plot. Both predict rainfall excess "reasonably well."

Classification: Multiple discrete events.

Location: Arizona.

Input Data Requirements: Saturated value of hydraulic conductivity.

Data Base for Calibration: See Limitations on Data Base.

Limitations on Data Base: A 6-foot x 12-foot runoff plot was used.

Calibration Results: Graphical and tabular.

Comments: None.

189. Smith, R. L., and G. E. Hauser. 1976. Calculation of flood discharges and flood hydrographs in Kansas. 174 pp. University of Kansas Center for Research, Inc., Lawrence.

Abstract: A method is presented which has the form of the rational equation, where the components are defined by relationships developed in the report. Peak discharge may be predicted for return periods of 2, 5, 10, 25, 50, and 100 years. A triangular hydrograph can then be derived.

Classification: Empirical equations.

Location: Kansas.

Input Data Requirements: Area of watershed; intensity of rainfall excess; ratio of peak discharges to the equilibrium discharge, determined from slope of precipitation vs. time curve for designated frequency.

Data Base for Calibration: 110 watersheds; 17-year average.

Limitations on Data Base: $531 \leq$ area of watershed $\leq 1{,}198{,}000$ acres; $15.8 \leq$ mean annual precipitation (rainfall) ≤ 41.2 inches; $1.35 \leq$ length of main channel ≤ 148.68 miles; $0.045 \leq$ slope of watershed ≤ 1.770 percent.

Calibration Results: Graphical and tabular.

Comments: None.

190. Smith, R. L., and I. Jundi. 1976. Exploration of the transferability of the frequency-equivalent non-linear hydrograph method for calculating flood frequency relationships. 83 pp. University of Kansas Center for Research, Inc., Lawrence.

Abstract: The transferability of flood frequency predictive equations developed by application of the frequency-equivalent non-linear hydrograph (FENL-H) method is explored. FENL-H calculates both a peak discharge and a triangular design hydrograph of specified frequency. FENL-H methodology is applied with mixed success in three regions with distinctly different climatic and geologic characteristics.

Classification: Single storm event: rain frequency $\propto$ runoff frequency.

Location: Kansas, Wisconsin, Illinois, Indiana, New York, New Jersey, Pennsylvania, Vermont, Maine, Delaware.

Input Data Requirements: Drainage area; length of watershed; slope of watershed; mean annual precipitation; and the rainfall-intensity-duration curve for the designated frequency.

Data Base for Calibration: 101 watersheds.

Limitations on Data Base: $3{,}469 \leq$ area of watershed $\leq 1{,}198{,}000$ acres; $13{,}200 \leq$ length of main channel $\leq 785{,}004$ feet; $0.017 \leq$ slope of main channel ≤ 1.921 percent; $17.0 \leq$ mean annual precipitation (inches of rainfall) ≤ 52.9 inches.

Calibration Results: Standard errors--Q_2, 0.15 of log cycle; Q_{25}, 0.25 of log cycle.

Comments: The method also includes a capability for determining a triangular hydrograph for design. The prediction equations should not be used in regions where peak flows are known to be less than 15 cubic feet per second per square mile.

191. Smith, R. L., K. E. Larson, G. E. Hauser, and I. Jundi. 1976. Relating flood frequency to precipitation frequency. Paper presented at the Second Annual Midwestern Meeting, American Geophysical Union, Oct. 22, 1976, Ann Arbor, Mich.

Abstract: A unit hydrograph method, FENL-H, is presented, where the peak discharge and time base are estimated using empirical formulas.

Classification: Single storm event: rain frequency$\propto$runoff frequency.

Location: Eastern United States.

Comments: Not evaluated.

192. Soil Conservation Service. 1969. Computer program for project formulation-hydrology. Technical Release No. 20, Supplement No. 1, Central Technical Unit. Washington, D. C.

Abstract: The program computes surface runoff resulting from any synthetic or natural rain storms. It develops flood hydrographs, routes through stream channels and reservoirs, and combines hydrographs with those from tributaries. It provides peaks and/or flood hydrographs, their time of occurrence, and water surface elevations at any desired cross section or structure. The program was developed to analyze a watershed under present conditions and future conditions with combinations of land cover/use, structural and/or channel modifications.

Classification: Single storm event: rain frequency$\propto$runoff frequency.

Location: Entire United States.

Input Data Requirements: Storm rainfall depths, durations, and distributions; SCS runoff curve numbers; time of concentration; dimensionless unit hydrograph; reach lengths; convex method routing coefficients or elevation discharge-area data for cross sections; storage-discharge data for reservoirs; baseflow.

Data Base for Calibration: See Comments.

Limitations on Data Base: Not specified.

Calibration Results: Not specified.

Comments: Runoff curve numbers are a function of land use and treatment or practice, hydrologic condition, hydrologic soil group, and antecedent moisture conditions. SCS project-size watersheds generally range up to 400 square miles.

193. Soil Conservation Service. 1970. Estimating peak discharges for watershed evaluation storms and preliminary designs. WTSC Technical Note-Hydrology-PO-2. West Technical Service Center, Portland, Oreg.

Abstract: Graphs are provided to estimate peak rates of runoff given the time of concentration and the identification of one of four standard SCS 24-hour precipitation distributions.

Classification: Single storm event: rain frequency$\propto$runoff frequency.

Location: Western States.

Input Data Requirements: Storm rainfall depth, SCS runoff curve number, time of concentration, drainage area.

Data Base for Calibration: Not specified.

Limitations on Data Base: Not specified.

Calibration Results: Not specified.

Comments: The method assumes the frequency of the peak is equal to the frequency of the rainfall intensity. The method assumes that runoff can be represented by one curve number for the watershed, meaning the land use, cover, and soils are similar and distributed uniformly throughout the watershed. The graphs were developed using Technical Release 20 (see reference 192) with a 0.5-hour time increment definition of the rainfall distributions.

194. Soil Conservation Service. 1971. Procedure to determine instantaneous peak flow for flatland areas. EWP Technical Guide No. 40, 5 pp. South Technical Service Center, Fort Worth, Tex.

Abstract: A method is presented to determine the instantaneous peak discharge from the maximum 24-hour average removal rate based on the Cypress Creek formula (see reference 205), which is an empirical coefficient based on the 24-hour runoff times the drainage area to the 5/6 power. A graph is provided for evaluating the relationship between the instantaneous peak and the 24-hour average removal rate.

Classification: Empirical equations.

Location: Flatland areas of southeastern United States.

Input Data Requirements: 24-hour rainfall; SCS runoff curve number; drainage; area.

Data Base for Calibration: Not specified.

Limitations on Data Base: Not specified.

Calibration Results: Not specified.

Comments: The method assumes that the return period of runoff equals that of the rainfall. The method was developed for flatland areas in the southeastern United States.

195. Soil Conservation Service. 1972. Hydrographs. National Engineering Handbook, section 4, Hydrology, chapter 16. Washington, D.C.

Abstract: The SCS peak rate equation is developed for use with the dimensionless unit hydrograph which has 37.5 percent of its total volume in the rising side. The constant 484 is known to vary from about 600 in steep terrain to 300 in very flat swampy country.

Classification: Empirical equations.

Location: Entire United States.

Input Data Requirements: Drainage area, runoff volume, time to peak (Tp).

Data Base for Calibration: Not specified.

Limitations on Data Base: Not specified.

Calibration Results: Not specified.

Comments: Variations of the equation use either time of concentration (Tc) or watershed lag and a unit duration of excess rainfall (ΔD). The ΔD is defined as being approximately equal to 0.133 Tc. The equation has been used to estimate peak flows from uniformly shaped watersheds no greater than 20 square miles that are hydrologically homogeneous in land use, soils, and drainage pattern.

196. Soil Conservation Service. 1972. Water supply forecasting. National Engineering Handbook, section 22, Snow survey and water supply forecasting, chapter 6. Washington, D.C.

Abstract: Chapter discusses the significance of forecasting variables, types of forecasts, the development of forecast formulas for both peaks and volume, errors in forecasting, and the accuracy of forecasting. A regression approach to forecast model development is recommended.

Classification: Statistical estimation of Q_p.

Location: Snowmelt water supply forecasting areas.

Input Data Required: Variables discussed include snow water equivalent; soil moisture; precipitation (fall, winter, spring); antecedent streamflow; baseflow; temperature; wind; radiation; and relative humidity.

Data Base for Calibration: Not specified.

Limitations on Data Base: Not specified.

Calibration Results: Not specified.

Comments: An individual forecast formula can be developed for each forecast unit from this guide.

197. Soil Conservation Service. 1973. A method for estimating volume and rate of runoff in small watersheds. Technical Paper 149. Washington, D.C.

Abstract: A method is given for estimating peak discharge for a small watershed from charts based on drainage area, 24-hour rainfall, watershed slope, and SCS runoff curve number. The SCS standard type I and type II storm distributions are presented.

Classification: Single storm event: rain frequency$\propto$runoff frequency.

Location: Entire United States.

Input Data Requirements: See Abstract.

Data Base for Calibration: Not specified.

Limitations on Data Base: Not specified.

Calibration Results: Not specified.

Comments: Method is applicable to ungaged basins of less than 2,000 acres and slopes less than 30 percent and where peaks are less than 2,000 cubic feet per second. Runoff curve number is a function of land use and treatment, hydrologic condition, soil group, and antecedent moisture condition. The design charts were formulated by the incremental triangular unit hydrograph summation method, which is illustrated. The method uses an empirical relationship between hydraulic length and drainage area, developed from experimental agricultural watersheds, for a natural watershed shape factor.

198. Soil Conservation Service. 1975. Urban hydrology for small watersheds. Technical Release No. 55. Washington, D.C.

Abstract: Three shortcut methods for estimating peak discharge on small watersheds, rural or urban, using SCS techniques are given. Chapter 5 presents the tabular routing method (see reference 195) for developing a composite flood hydrograph at any point within a watershed, using subareas, time of concentration, reach travel times, and prerouted hydrograph unit discharge values. Chapter 5 also contains a graphical method (see reference 193) to determine peak discharges given the time of concentration. Appendix D presents charts for estimating peak rates of runoff based on drainage area, slope, and curve number. Adjusting factors for slope interpolation, swampy and ponding areas, and watershed shape are given in appendix E.

Classification: Single storm event: rain frequency$\propto$runoff frequency.

Location: Entire United States.

Input Data Requirements: Storm rainfall depth; SCS runoff curve numbers; time of concentration and travel times (tabular and graphical methods only); slope (charts only).

Data Base for Calibration: See Comments.

Limitations on Data Base: Not specified.

Calibration Results: Not specified.

Comments: The SCS standard 24-hour, type II storm distribution is used in all three methods. The charts in appendix D are limited to drainage areas less than 2,000 acres. The size of watersheds used in the tabular method is limited to subarea time of concentrations (Tc) less than 2 hours and travel times less than 4 hours to the watershed outlet. The graphical method limits Tc to less than 5 hours. The prerouted hydrograph table and the graph (peak vs. Tc) were developed using Technical Release 20 (see reference 192) with a 0.1 time increment definition of the rainfall distribution.

199. Soil Conservation Service. 1976. Tabular method of flood routing 24-hour type II storm distribution. NETSC Technical Note, Engineering-UD-20 (rev.). Northeast Technical Service Center, Broomall, Pa.

Abstract: Tabular method of approximate flood routing is used primarily to rapidly show the effects of structures and combinations of structures on peak discharges at different places in the watershed. Composite flood hydrographs can be developed using subareas, time of concentration, reach travel times, and prerouted hydrograph unit discharge values. The prerouted subarea unit discharge values are selected from tables, converted to discharge by multiplying by drainage area and runoff volume, tabulated, and combined to determine peak values.

Classification: Single storm event: rain frequency$\propto$runoff frequency.

Location: Entire United States.

Input Data Requirements: For each subarea--24-hour rainfall, SCS runoff curve number (RCN), drainage area, and time of concentration (Tc), travel time (Tt) for each reach; and the maximum release rate for each proposed structure.

Data Base for Calibration: Not specified.

Limitations on Data Base: Not specified.

Calibration Results: Not specified.

Comments: The prerouted tables were developed using Technical Release 20 (see reference 192) with an RCN of 70, a runoff volume of 3 inches, a convex routing coefficient of 0.5, and the SCS standard 24-hour, type II storm distribution. Tabular unit discharges are given for subareas with a range of Tc of 0.1 to 12 hours and valley routing time from 0 to 30 hours. The tabular method should not be used when runoff volumes are less than 1 inch.

200. Sokolov, A. A., S. E. Rantz, and M. Roche. 1976. Floodflow computation. Studies and Reports in Hydrology No. 22, 295 pp. UNESCO Press, Paris, France.

Abstract: Paper describes methods used in the U.S.S.R., Italy, Algeria, central and southwest Africa, Central America, Spain, France, Canada, and United States for floodflow estimation and analysis where streamflow data are inadequate.

Classification: Not classified.

Location: See Abstract.

Comments: Not evaluated.

201. Southeastern Wisconsin Regional Planning Commission. 1974. Floodland information report for the Rubicon River. Community Assistance Planning Report No. 4, 81 pp. Waukesha, Wis.

Abstract: Report presents the development and analysis of flood plain information for the Rubicon River within and near Hartford, Wis. A hydraulic-hydrologic model, Hydrologic Engineering Center-2 (HEC-2), based on SCS Technical Release 20, is used.

Classification: Single storm event: rain frequency$\propto$runoff frequency.

Location: Rubicon River Basin, Wis.

Input Data Requirements: A data inventory included precipitation, runoff, soils, land use, delineation of subbasins, stream channel profiles, flood land cross sections, roughness coefficients, and bridge, culvert, and dam descriptions.

Data Base for Calibration: Not specified.

Limitations on Data Base: Not specified.

Calibration Results: See Comments (1).

Comments: (1) The results were compared with the USGS regression equations; the regression estimates of Q_{10}, Q_{25}, and Q_{50} were 72, 74, and 81 percent of the estimates from the hydraulic-hydrologic model. (2) The hydraulic-hydrologic model consisted of two submodels: (a) hydraulic submodel used to determine the hydraulic characteristics of the flood plain (HEC-2) and (b) a hydrologic submodel used to convert design storms into discharges (SCS Technical Release 20).

202. Southeastern Wisconsin Regional Planning Commission. 1976. Floodland information report for the Pewaukee River. Community Assistance Planning Report No. 9, 43 pp. Waukesha, Wis.

Abstract: A watershed simulation model and a hydraulic submodel for determining flood stages are used to predict peak discharge and stage for selected return periods in the year 2000 under proposed land use changes.

Classification: Continuous record.

Location: Wisconsin.

Comments: Not evaluated.

203. Stankowski, S. J. 1974. Magnitude and frequency of floods in New Jersey with effects of urbanization. U.S. Geological Survey Special Report No. 38, 46 pp. Washington, D.C.

Abstract: Regression equations are developed for relating flood peaks of return periods 2, 5, 10, 25, 50, and 100 years to basin area, channel slope, lake and swamp areas, and an index of impervious cover. The relations are applicable to both urban and rural areas and have an average standard error ranging from 48 to 54 percent.

Classification: Statistical estimation of Q_p.

Location: New Jersey.

Input Data Requirements: Area of watershed; slope of main channel determined between 10 and 85 percent points of main channel length; surface area of ponds, lakes, and swamps; index of impervious cover.

Data Base for Calibration: 103 watersheds; 27-year average, 6-year minimum, 74-year maximum.

Limitations on Data Base: $0.63 \leq$ area of watershed ≤ 779 square miles; $1.83 \leq$ slope ≤ 275 feet per mile; $1.00 \leq$ surface area of ponds, lakes, and swamps ≤ 29.4 percent; $1.00 \leq$ index of impervious cover ≤ 72 percent.

Calibration Results: Average standard error--48 to 54 percent.

Comments: Method is applicable to both urban and rural streams. A method is presented for estimating index of impervious cover from population density of the watershed.

204. Stephens, J. C., and W. C. Mills. 1965. Using the Cypress Creek formula to estimate runoff rates in the southern coastal plain and adjacent flatwoods land resource areas. U.S. Agricultural Research Service Publication No. ARS 41-95, 17 pp. Washington, D.C.

Abstract: An empirical relationship between peak discharge and drainage area is discussed.

Classification: Empirical equations.

Location: Southern coastal plain.

Input Data Requirements: Area (square miles). See Comments (1).

Data Base for Calibration: Three basins; 10 events on basin W-1 and five events on basin W-3.

Limitations on Data Base: Areas of test basins--78.0, 98.6, and 15.6 square miles; with slopes from 0 to 2 percent.

Calibration Results: Not specified.

Comments: (1) $Q_p = CA^{5/6}$ where C is an empirical constant, which varies with land use. (2) From 20 storm events, annual maximum 24-hour average runoff rates were plotted against drainage area. Curves were provided for return periods of 2, 10, and 50 years.

205. Stephens, J. C., and W. C. Mills. 1966. Evaluating and applying the Cypress Creek drainage formula. American Society of Agricultural Engineers Transactions 9(4):550-555.

Abstract: Paper evaluates a graphical analysis between peak discharge and drainage area as applied to watersheds in the southern coastal plain.

Classification: Empirical equations.

Location: Florida.

Comments: Not evaluated.

206. Stevens, J. N. 1976. Procedure for making discharge calculations for HUD-flood insurance studies. Unpublished paper, 2719 Lance Court, South Bend, Ind. 46628.

Abstract: Paper presents an empirical procedure that uses elements of the SCS method. The procedure has not been tested.

Classification: Statistical estimation of Q_p.

Location: Pennsylvania, Indiana.

Input Data Requirements: Area of watershed; process of percolation to groundwater; slope of main channel; drainage density; length of main channel; time of concentration; slope of watershed; SCS runoff curve number.

Data Base for Calibration: Not specified.

Limitations on Data Base: See Comments (2).

Calibration Results: Not specified.

Comments: (1) Unpublished paper describes procedures used in HUD-flood insurance studies in Pennsylvania and Indiana. (2) Although not specified, the use of some empirical equations would suggest that it is applicable to basins less than 20 square miles.

207. Surkan, A. J. 1969. Synthetic hydrographs: Effects of network geometry. Water Resources Research 5(1):112-128.

Abstract: A mathematical model for channel networks represented by directed graphs on a rectangular grid is used to generate synthetic hydrographs. This makes possible simulation of either the effects of changes in geometric factors or the effects of different types and motions of storms. The model provides for a discrete approximation of a distributed network, a transformation relating the runoff hydrograph and input precipitation. Only a single parameter, which is associated with the collection and release of water, is required.

Classification: Single storm event: rain frequency $\propto$ runoff frequency.

Location: Maryland.

Comments: Not evaluated.

208. Susquehanna River Basin Study Coordinating Committee. 1970. Susquehanna River Basin Study: Appendix D--Hydrology, chapter IV. U.S. Army Corps of Engineers, Baltimore, Md.

Abstract: Regression equations are provided for predicting the mean and standard deviation of the logarithms using station data and concepts of cross-correlation. A constant skew is assumed. The regression constants are spatially varied, with the maps provided. The significance of the constants is not tested.

Classification: Statistical estimation of moments.

Location: Susquehanna River Basin north of the Pennsylvania-Maryland State line.

Input Data Requirements: Drainage area; location; length of longest stream; distance from Pennsylvania-Maryland State line.

Data Base for Calibration: 104 stations; average observed record, 33 years; minimum record, 10 years; maximum record, 74 years.

Limitations on Data Base: Drainage area>14 square miles.

Calibration Results: Coefficient of determination for mean = 0.9471; coefficient of determination for standard deviation = 0.4156.

Comments: None.

209. Thomas, C. A., W. A. Harenberg, and J. M. Anderson. 1973. Magnitude and frequency of floods in small drainage basins in Idaho. U.S. Geological Survey Water Resources Investigations 7-73, 61 pp. Boise, Idaho.

Abstract: Regression equations are developed for eight regions of Idaho and relate a 10-year flood peak to basin characteristics. The ratios between the 50- and 25-year floods and the 10-year flood are given for the eight regions. The method is applicable only to areas of 0.5 to 200 square miles.

Classification: Index flood method.

Location: Idaho.

Input Data Requirements: Regions 1 and 5--area of watershed; Regions 2 and 4--area of watershed, forest cover factor; Regions 3 and 8--area of watershed, forest cover factor, latitude of centroid of basin; Region 6--area of watershed, surface area of ponds, lakes, and swamps; Region 7--area of watershed, longitude of centroid of basin.

Data Base for Calibration: 303 watersheds; 10-year minimum or extended to 10 years.

Limitations on Data Base: 0.5<area<200 square miles.

Calibration Results:

	Region							
	1	2	3	4	5	6	7	8
Standard error of estimate (percent)	41	61	51	62	61	41	59	45

Comments: Both stepforward and stepbackward multiple regression were used. The area of study was divided into eight regions based on the residuals from stepforward regression. It is not clear either from text or accompanying diagrams how many of the 303 gaging stations apply to each region. The entire State is not covered by the regression equations. Comparisons of computed and "actual" data for calibration results were made using log-Pearson Type III frequency curves.

210. Thomas, D. M., and M. A. Benson. 1975. Generalization of streamflow characteristics from drainage-basin characteristics. U.S. Geological Survey Water Supply Paper 1975, 55 pp. Washington, D.C.

Abstract: A set of regression equations are developed for four regions of the United States for various return periods up to 50 years. The equations relate basin characteristics to peak discharge. Other streamflow characteristics can also be determined from additional regression equations presented.

Classification: Statistical estimation of Q_p.

Location: West Virginia, Maryland, Virginia, Pennsylvania.

Input Data Requirements: Area of watershed (square miles); slope of main channel determined between 10 and 85 percent points of main channel length (feet per mile); length of main channel (miles); surface storage area of ponds, lakes, and swamps (percent); soil infiltration index; 2-year,24-hour rainfall intensity (inches); mean annual snowfall (inches); forest cover factor.

Data Base for Calibration: 41 watersheds; 18-year minimum.

Limitations on Data Base: Not specified.

Calibration Results: Standard error of estimate--19.2 to 39.2 percent.

Comments: Other streamflow characteristics can also be determined from additional regression equations presented. The standard errors presented are the best obtainable for a combination of the variables of input data requirements. All variables were not necessarily used for any or all equations, but each variable is present in at least one equation.

211. Thomas, W. O., Jr., and Corley, R. K. 1977. Techniques for estimating flood discharges for Oklahoma streams. U.S. Geological Survey Water Resources Investigations 77-54, Oklahoma City.

Abstract: Regression analysis is used to determine flood peak for selected return periods using basin and meteorologic characteristics as input.

Classification: Statistical estimation of Q_p.

Location: Oklahoma.

Comments: Not evaluated.

212. Todorovic, P., and J. Rousselle. 1971. Some problems of flood analysis. Water Resources Research 7(5):1144-1150.

Abstract: A model is developed for nonidentically distributed exceedences on the assumption that only those exceedences during a particular season may be considered identically distributed. From this hypothesis the distribution function of the maximum flood peak exceedence in an arbitrary interval of time is determined. The results are then applied to the 72-year record of the Greenbriar River at Alderson, W. Va.

Classification: Not classified.

Location: West Virginia.

Comments: Not evaluated.

213. Todorovic, P., and D. A. Woolhiser. 1972. On the time when the extreme flood occurs. Water Resources Research 8(6):1433-1438.

Abstract: A stochastic description of floods is incomplete without the distribution of the time of occurrence of the momentary peak discharge within a year or an arbitrary interval of time. The one-dimensional distribution function and the mathematical expectation are determined for the case in which individual flood exceedences are independent, identically distributed random variables.

Classification: Not classified.

Location: West Virginia.

Comments: Not evaluated.

214. Todorovic, P., and E. Zelenhasic. 1970. A stochastic model for flood analysis. Water Resources Research 6(6):1641-1648.

Abstract: A stochastic model, based on the recent developments in the Theory of Extreme Values, is presented to describe and analyze excessive streamflows. The results are applied on the 72-year record of the Susquehanna River at Wilkes-Barre, Pa.

Classification: Not classified.

Location: Pennsylvania.

Comments: Not evaluated.

215. U.S. Army Corps of Engineers. 1960. HEC-1, Flood hydrograph package. Hydrologic Engineering Center, Davis, Calif.

Abstract: HEC-1 is the first in a series of package programs developed by HEC to incorporate all the basic flood hydrograph computations associated with a single recorded or hypothetical storm into a single unit. The capabilities of the program are (1) hydrograph generation based on the unit hydrograph approach, including unit hydrographs computed from time-area curves; (2) hydrograph combining and routing through channels and reservoirs via a number of alternate methods; (3) rainfall, snowfall, snowpack, and snowmelt determinations.

Classification: Single storm event: rain frequency$\propto$runoff frequency.

Location: Entire United States.

Comments: Not evaluated.

216. U.S. Army Corps of Engineers. 1962. Adjustment of frequency statistics. Civil Works Investigations Project No. 151, Flood Volume Studies-West Coast, Research Note No. 5, 4 pp. Sacramento, Calif.

Abstract: Equations are given for determining statistics of short records based on correlation with a long record. Included are mean, standard deviation, and the equivalent length of record.

Classification: Statistical estimation of moments.

Location: Not specified.

Input Data Requirements: (1) Mean of record 1; mean of record 2; mean of data of record 2 that correspond with record 1; coefficient of correlation between records 1 and 2 for period of record 1; standard deviation of record 1; standard deviation of data of record 2 that correspond with record 1; (2) number of years of record 1 before extension; (3) standard deviation of record 2; standard deviation of data of record 2 that correspond with record 1; coefficient of correlation between records 1 and 2 for period of record 1; standard deviation of record 1.

Data Base for Calibration: Not specified.

Limitations on Data Base: Not specified.

Calibration Results: Not specified.

Comments: None.

217. U.S. Army Corps of Engineers. 1962. Generalized snowmelt runoff frequencies. Civil Works Investigations Project No. 151, Flood Volume Studies-West Coast, Technical Bulletin No. 8, 50 pp. Sacramento, Calif.

Abstract: Report gives methods for determining runoff resulting from snowmelt using design charts provided for parts of Washington, Oregon, California, Nevada, and Idaho.

Classification: Statistical estimation of Q_p.

Location: Washington, Oregon, California, Idaho, Nevada.

Input Data Requirements: Elevation of average April 1 snowline above sea level; area of watershed above the average April 1 snowline.

Data Base for Calibration: 192 watersheds; 7-year minimum, 62-year maximum.

Limitations on Data Base: $6.1 \leq$ area of watershed $\leq 13{,}700$ square miles; $4 \leq$ area of watershed above the average April 1 snowline $\leq 12{,}295$ square miles.

Calibration Results: Not specified.

Comments: Regional skew coefficients are used instead of station skew. Data from adjacent stations with long records are used to adjust means and standard deviations. Statistics related to physiographic characteristics and residuals are regionalized. Index ratio method is used with seasonal maximum runoff to derive frequency curve.

218. U.S. Army Corps of Engineers. 1964. Maximum annual flood frequencies for Portland District. Office Report No. 1 on Flood Frequency, 24 pp. (Revised April 1965.) Office of the District Engineer, Portland, Oreg.

Abstract: Stochastic technique provides quick estimation of peak discharge using regional charts. Charts are provided for Oregon only.

Classification: Index flood estimation.

Location: Oregon.

Input Data Requirements: Area of watershed; mean annual rainfall.

Data Base for Calibration: 110 watersheds; 17-year minimum.

Limitations on Data Base: Not specified.

Calibration Results: Not specified.

Comments: Large quantities of data are needed to construct the charts for interpretation.

219. U.S. Army Corps of Engineers. 1966. Study of runoff from bottom land and hillside terrain. Civil Works Investigations Project ES-180, 97 pp. Kansas City District, Kansas City.

Abstract: A technique is presented for predicting peak flows on any size basin using a modification of the method developed by Chow (see reference 28). Applicable only to those floods caused wholly by rainfall. Also, 24-hour and 30-day runoff can be predicted.

Classification: Empirical equations.

Location: Not specified.

Comments: Not evaluated.

220. U.S. Army Corps of Engineers. 1969. Procedure for determination of maximum annual flood peak and volume frequencies for Portland District. Report No. 2, 25 pp. Portland, Oreg.

Abstract: Stochastic technique provides for quick estimate of peak discharge using regional charts. Charts are provided for Oregon only.

Classification: Index flood estimation.

Location: Oregon.

Input Data Requirements: Area of watershed; mean annual rainfall.

Data Base for Calibration: 163 watersheds; 15-year minimum.

Limitations on Data Base: Not available.

Calibration Results: Not available.

Comments: An extensive regional data base is needed to construct the charts for interpolation. This report is a supplement to reference 218, incorporating more data and also making possible a prediction of flood peak of 1, 2, 4, 8, or 16 days in addition to instantaneous flow. Conclusion is that revision of regional study should be made after a record flood or when record length changes by 25 percent.

221. U.S. Army Corps of Engineers. 1975. Hydrologic study tropical storm Agnes. North Atlantic Division, New York.

Abstract: Regression analyses are performed for predicting the mean and standard deviation of the logs of an annual series. The drainage area is found to be the most significant variable for predicting the mean, while the basin length is the most significant variable for predicting the standard deviation. Because of the high correlation with length, an equation with area is used to predict both moments.

Classification: Statistical estimation of moments.

Location: James, Potomac, Susquehanna, and Delaware River Basins.

Input Data Requirements: Location, drainage area.

Data Base for Calibration: 199 watersheds.

Limitations on Data Base: $20<\text{drainage area}<1{,}200$ square miles.

Calibration Results: Coefficient of determination = 0.835 for the mean; no value given for the standard deviation.

Comments: A map of the skew coefficient is provided.

222. U.S. Army Corps of Engineers. 1975. Standard project flood determinations. Civil Engineer Bulletin No. 52-8, 56 pp. Washington, D.C.

Abstract: Techniques are discussed for determining the standard project storm and the standard project flood. The relationship between the standard project flood and the design flood is also discussed.

Classification: Index flood estimation.

Location: United States.

Comments: Not evaluated.

223. U.S. Department of the Army. 1957. The construction of unit graphs without discharge records. Technical Bulletin No. 5-550-3, Flood Prediction Techniques, chapter 6. 215 pp. Washington, D.C.

Abstract: This chapter discusses the development of synthetic unit graph relations using Snyder's method and two additional methods that introduce a slope factor and modify Snyder's equations.

Classification: Single storm event: rain frequency$\propto$runoff frequency.

Location: United States.

Input Data Requirements: L = length of longest watercourse; L_{ca} = shape factor; C_t and C_p = empirical coefficient.

Data Base for Calibration: Not specified.

Limitations on Data Base: Not specified.

Calibration Results: None.

Comments: None.

224. U.S. Nuclear Regulatory Commission. 1976. Design basis for floods for nuclear power plants. Regulatory Guide 1.59, Revision 1, 79 pp. Office of Standards Development, Washington, D.C.

Abstract: This guide discusses the design basis for floods for nuclear power plants such that they can withstand without loss of capability for cold shutdown and maintenance. Appendix A outlines the nature and scope of detailed hydrologic engineering activities involved in determining estimates for the probable maximum flood and for seismically induced floods resulting from dam failures and describes the situations for which less extensive analyses are acceptable. Appendix B gives time saving alternative methods of estimating the probable maximum flood along streams. Appendix C gives a simplified method of estimating probable maximum surges on the Atlantic and Gulf Coasts.

Classification: Not classified.

Location: Entire United States.

Comments: Not evaluated.

225. Utah Department of Transportation. 1976. Hydrologic design of culverts. Unpublished paper. Salt Lake City, Utah.

Abstract: An empirical procedure is used by the Utah Department of Transportation for culvert design in areas draining less than 2 square miles.

Classification: Empirical equations.

Location: Utah.

Input Data Requirements: See Comments.

Data Base for Calibration: Not specified.

Limitations on Data Base: Area$\leq$2 square miles.

Calibration Results: Not specified.

Comments: $Q_f = Q_c \times LF \times FF$ where Q_f = design discharge (cubic feet per second), Q_c = discharge from chart, LF = land factor, and FF = frequency factor. Charts and tables are used which involve factors including topography, 25-year, 60-minute rainfall intensity, area, geographic location, and typical terrain characteristics.

226. Viessman, W., Jr. 1968. Runoff estimation for very small drainage areas. Water Resources Research 4(1):87-93.

Abstract: A function for peak discharge and a function relating flow with time, peak discharge, and recession constant are developed. An equation is derived from impervious area data for K and tested on an experimental agricultural plot, giving good results for the unit hydrograph.

Classification: Single storm event: rain frequency$\propto$runoff frequency.

Location: See Comments.

Input Data Requirements: Not specified.

Data Base for Calibration: Four watersheds; 2 to 37 storms on each watershed.

Limitations on Data Base: 12$\leq$length of main channel$\leq$916 feet; 0.1$\leq$slope of main channel$\leq$4.0 percent; 0.015$\leq$Manning's roughness coefficient$\leq$0.020.

Calibration Results: Graphical results appear very good.

Comments: Equation is applicable primarily to urban areas. Basis is the linear reservoir concept. The single parameter that is required to define a unit hydrograph was found to be a function of Manning's roughness coefficient, the maximum gutter flow distance or flow length, and mean gutter slope.

227. Wahl, K. L. 1976. Accuracy of channel measurements and the implications in estimating streamflow characteristics. Unpublished paper, U.S. Geological Survey, Washington, D.C.

Abstract: The effect of channel measurement error on estimation of peak discharge is evaluated. Of three reference levels, none proved to be superior. A standard error of about 30 percent in estimated discharge can be expected from the sampling error in width measurements by trained individuals.

Classification: Statistical estimation of Q_p.

Location: Wyoming.

Input Data Requirements: Width of channel at point of streamflow estimation; depth of channel at point of streamflow estimation.

Data Base for Calibration: 22 watersheds.

Limitations on Data Base: Not available.

Calibration Results: See Comments.

Comments: The effect of channel measurement error on estimation of peak discharge was evaluated at 22 Wyoming sites by seven participants. Three reference levels were used: low bar, active channel, main channel. None proved to be superior. It was found that width measurements were more consistent than depth. A standard error of about 30 percent in estimated discharge can be expected from the sampling error in width measurements by trained individuals. To predict Q, the following relationship is used: $\log Q = \log a + b \log W$, where W is the width of the channel.

228. Walker, P. N. 1971. Flow characteristics of Maryland streams. Report of Investigations No. 16, 160 pp. Maryland Geological Survey, Baltimore.

Abstract: Multiple regression equations for return periods of 2, 5, 10, 25, 50, and 100 years are presented. The equations relate peak discharge to basin area, channel slope, forest cover, and a geographical factor.

Classification: Statistical estimation of Q_p.

Location: Maryland.

Input Data Requirements: Area of watershed (square miles); slope of main channel determined between 10 and 85 percent points of main channel length (feet per mile); forest cover factor; factor which varies with geographic region. (Forest cover factor not significant for 100-year flood.)

Data Base for Calibration: Not summarized.

Limitations on Data Base: Not summarized.

Calibration Results:

	Return period (years)					
	2	5	10	25	50	100
Standard error (percent)	3.17	30.5	32.4	37.4	36.7	38.4

Comments: None.

229. Wandle, S. W., Jr. 1977. Estimating the magnitude and frequency of floods on natural-flow streams in Massachusetts. U.S. Geological Survey Water Resources Investigations 77-39, 49 pp. Boston, Mass.

Abstract: Regression analysis is used to determine flood peak for selected return periods using basin and meteorologic characteristics as input.

Classification: Statistical estimation of Q_p.

Location: Massachusetts.

Comments: Not evaluated.

230. Watt, W. E., and R. J. Kennedy. 1969. A peak discharge relation for intermediate drainage basins. Water Resources Research 5(6):1406-1409.

Abstract: Paper finds that the ratio of peak flow to precipitation excess could be related to a single variable--basin lag time--for intermediate size watersheds.

Classification: Empirical equations.

Location: Ontario.

Input Data Requirements: Basin lag time.

Data Base for Calibration: 12 watersheds; 45 storms.

Limitations on Data Base: 10<time lag<60 hours.

Calibration Results: Very good agreement with observed data.

Comments: None.

231. Webber, E. E., and W. P. Bartlett, Jr. 1976. Floods in Ohio: Magnitude and frequency. Ohio State and U.S. Geological Survey, unpublished open-file report 76-768. Columbus, Ohio.

<u>Abstract</u>: Regression analysis is used to determine flood peak for selected return periods using basin and meteorologic characteristics as input.

<u>Classification</u>: Statistical estimation of Q_p.

<u>Location</u>: Ohio.

<u>Comments</u>: Not evaluated.

232. Webber, E. E., and R. I. Mayo. 1973. Flood magnitude and frequency on small streams in Ohio: A progress report. U.S. Geological Survey Administrative Report, 16 pp. Columbus, Ohio.

<u>Abstract</u>: Paper discusses index flood method using mean annual flood as index flood. Standard errors range from approximately 30 to 40 percent.

<u>Classification</u>: Index flood estimation.

<u>Location</u>: Ohio.

<u>Input Data Requirements</u>: Slope of main channel; area of watershed; soil; mean elevation between the 10 and 85 percent points of the main channel length.

<u>Data Base for Calibration</u>: 90 watersheds; 5-year minimum at each station.

<u>Limitations on Data Base</u>: Area of watershed<50 square miles.

<u>Calibration Results</u>: Standard errors--mean annual flood (return period = 2.33 years) $\pm$ 30 percent; 5-year frequency peak flow $\pm$ 32 percent; 10-year frequency peak flow $\pm$ 38 percent.

<u>Comments</u>: No areas in mining or farm land are included. A 2.33-year frequency peak flow and a 20-year frequency peak flow are calculated, and 5-year frequency peak flow and 10-year frequency peak flow are determined by interpolation on Gumbel extreme-value plots.

233. Wibben, H. C. 1976. Application of the U.S. Geological Survey rainfall-runoff simulation model to improve flood-frequency estimates on small Tennessee streams. U.S. Geological Survey Water Resources Investigations 76-120, 53 pp. Nashville, Tenn.

Abstract: The USGS rainfall-runoff simulation model is used in conjunction with climatological data to improve flood-frequency estimates for 52 small drainage basins in Tennessee. The basins range in size from 0.17 to 64 square miles. Model parameters are determined by calibration with observed data from each site. Average error of peak discharge simulation is about 36 percent.

Classification: Multiple discrete events.

Location: Tennessee.

Comments: Not evaluated.

234. Williams, T. T. 1971. Drainage correlation research project. 2 volumes, 486 pp. Department of Civil Engineering and Engineering Mechanics, Montana State University, Bozeman.

Abstract: An empirical procedure for estimating peak discharge from precipitation is evaluated for use in Montana.

Classification: Statistical estimation of Q_p.

Location: Montana.

Input Data Requirements: See Comments (1).

Data Base for Calibration: Not specified.

Limitations on Data Base: Not specified.

Calibration Results: See Comments (2).

Comments: (1) $Q_t = (R_i D_i / F_i)\tilde{Q}$ where R_i = rainfall intensity ratio, D_i = rainfall-discharge recurrence factor, F_i = rain-snow baseflow interaction ratio, $\tilde{Q}$ = mean annual peak discharge rate. All of these must be determined using figures given in the report or, in the case of $\tilde{Q}$, evaluated from streamflow records or regional analysis. It thus has the form of an index flood ratio. (2) While quantitative indices of goodness-of-fit were not provided, 26 of the 36 stations were within $\pm$ 39 percent of the value from an extreme value analysis.

235. Wiser, E. H. 1976. Regional simulation of streamflow data. American Society of Agricultural Engineers Paper No. 76-2084. St. Joseph, Mich.

Abstract: A control segment has been added to SSARR model to make it more accessible to planners and other nonhydrologists. The revised version, called NCSSARR, is calibrated and tested on 18 North Carolina watersheds, with the coefficient of correlation greater than 0.84 for all but two.

Classification: Continuous record.

Location: North Carolina.

Input Data Requirements: 24 parameters.

Data Base for Calibration: Two watersheds; 25 years of record.

Limitations on Data Base: 2.2$\leq$area of watershed$\leq$2,690 square miles.

Calibration Results: Coefficient of correlation of 0.90 and 0.92.

Comments: Snowmelt is one of the capabilities of SSARR but not of NCSSARR. A data-processing capability called HISARS is included in NCSSARR so that all results are stored in file. NCSSARR will approach a problem three ways: (1) if watershed has been previously routed the information will be taken from file; (2) the watershed will be routed ignoring the regulation segment if no regulation occurs, and (3) the watershed will be routed including regulation when regulation occurs.

236. Wolman, M. G. 1971. Evaluating alternative techniques of flood plain mapping. Water Resources Research 7(6):1383-1342.

Abstract: Methods of flood plain mapping are evaluated, with particular emphasis on the costs of the alternatives.

Classification: Not classified.

Location: Not specified.

Comments: Not evaluated.

237. Woo, D. C. 1974. Flood peak estimates from small rural watersheds. Public Roads 38(3):117-119.

Abstract: Paper discusses recent literature on methods of estimating peak flows on small watersheds.

Classification: Comparison of various techniques.

Location: Not specified.

Comments: Not evaluated.

238. World Meteorological Organization. 1975. Intercomparison of conceptual models used in operational hydrological forecasting. Operational Hydrology Report No. 7, 172 pp. Secretariat of the World Meteorological Organization, Geneva.

Abstract: The study tests 10 operational conceptual hydrological models on six river catchment data sets from climatological and geographically varied conditions. Each data set consists of two distinct periods: a calibration period (6 years) and a verification period (2 years). In addition to intercomparison of models, the report also makes recommendations and conclusions on model development, optimization techniques, and verification criteria.

Classification: Comparison of various techniques.

Location: Entire United States.

Input Data Requirements: Numerous for each model.

Data Base for Calibration: Six watersheds; 6 years for calibration, 2 years for verification.

Limitations on Data Base: Not specified.

Calibration Results: Varied with models and watershed.

Comments: None.

239. Wu, I-Pai. 1969. Flood hydrology of small watersheds: Evaluation of time parameters and determination of peak discharge. American Society of Agricultural Engineers Transactions 12(5):655-660.

Abstract: Equations are presented for estimating the peak discharge of an instantaneous UH or triangular UH, given surface runoff, basin area, and recession constant. A regression equation relates recession constant to basin area. The technique is developed for Hawaii.

Classification: Single storm event: rain frequency$\propto$runoff frequency.

Location: Hawaii.

Input Data Requirements: Equation 1--area of watershed; process of overland flow; recession constant for that part of recession curve caused by surface runoff; equation 2--area of watershed; process of overland flow; recession constant for that part of recession curve caused by surface runoff; equation 3--area of watershed.

Data Base for Calibration: 30 watersheds, 250 events.

Limitations on Data Base: $0.28 \leq$ area of watershed ≤ 45.70 square miles; $0.42 \leq$ recession constant for that part of recession curve caused by surface runoff ≤ 2.80 hours.

Calibration Results: Equations 1 and 2 "good" reliability; equation 3 not specified.

Comments: None.

240. Young, C. P., and J. Prudhoe. 1973. The estimation of flood flows from natural catchments. TRRL Report LR 565, 63 pp. Transport and Road Research Laboratory, Department of the Environment, Crowthorne, Berkshire, England.

Abstract: An empirical procedure for estimating peak discharge is presented. The formula requires as input the catchment length, slope, rainfall intensity of the frequency equal to the desired runoff frequency, and the average annual rainfall. The method is calibrated from storm events on five watersheds ranging in area from 3 to 21 square kilometers. The model was tested on 16 watersheds in England, which range in area from 10 to 90 square kilometers.

Classification: Statistical estimation of Q_p.

Location: England.

Input Data Requirements: Catchment length; dimensionless slope number; area; average annual rainfall; Bilham rainfall index.

Data Base for Calibration: Five stations.

Limitations on Data Base: $640 <$ average annual rainfall < 1110 millimeters; $2.77 <$ area < 21.33 square kilometers.

Calibration Results: See Comments (3).

Comments: (1) The Bilham rainfall index is the value of a rainfall duration-intensity-frequency relationship. (2) For the 2-year event, the ratio of the predictor to observed Q_p ranged from 0.55 to 2.16; for the 10-year event, 0.52 to 1.88. These values are based on 16 stations with areas ranging from 10.4 to 88.7 square kilometers. (3) The five catchments that were used in calibration were relatively impermeable, containing soils based on clays.

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